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PAPERS IN PHYSICAL OCEANOGRAPHY AND METEOROLOGY

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Vol. XII, No. 2

OBSERVATIONAL STUDIES OF THE AIR FLOW OVER NANTUCKET ISLAND DURING THE SUMMER OF 1950

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CAMBRIDGE AND WOODS HOLE, MASSACHUSETTS

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Especial gratitude is due Mr. Claude Ronne whose advice, help, and technical skill were responsible for the success of the photographic aspect of the program.

I. INTRODUCTION[1]

THE observations presented here were undertaken as a continuation of a broader program to investigate atmospheric convection. One phase of this study concerns the relation between convective motions, their energy sources, and the structure of the atmosphere prior to their onset. The structure of the atmosphere is described in terms of such parameters as temperature, humidity, velocity, turbulence, and distribution of these in space. An oceanic island was chosen as the site for this phase of the study primarily because it serves as a localized and clearly defined energy source for convective motions. Nantucket was selected from the many accessible islands in the Woods Hole area, nearly all known to produce convective cloud streets, mainly because of its flat, smooth topography. Because its elevation never exceeds 15 meters above sea level and because it contains no large trees, hills or other obstructions, the effect of heating the air from below is rather well isolated due to minimization of the barrier and frictional effects. Previous observational work (Malkus, Bunker, and McCasland, 1949)[2] indicates that such heating is the main energy source for the observed convective motions and constitutes a necessary but not sufficient condition for their production. This conclusion is corroborated and extended by the present data.

Other desirable features of Nantucket are its dimensions (see Figure 1). It ranges from 5 to 10 km in north-south extent and is just over 20 km long from east to west. Its relatively small size suggests that the scale of the convective motions produced will be small enough so that effects of the earth's rotation are not of primary importance, and its relatively greater east-west length suggests that for northerly or southerly winds it may behave nearly as an "infinitely wide" island.

The fact, then, that in the actual air flow over Nantucket many of the numerous complexities ordinarily affecting the air motion have been nearly eliminated, or at least to some degree controlled, means that fairly accurate theoretical and perhaps laboratory models of the flow may be constructed and tested against the real situation. Two preliminary theoretical studies have already appeared as technical reports (Malkus and Stern, 1951; Stern and Malkus, 1952)[3] and will soon be published. The second of these makes use of the present data in comparison with the theoretical predictions of the streamline flow over the island, especially in its relation to the development of a well-mixed ground layer. Parts of the data have been further used to study the structure and development of individual cumulus clouds. This work is discussed by Malkus (1952). The island convection problem, with emphasis on conditions for the downwind "lee waves" (made visible as cumulus streets if sufficient moisture is present) has been related to more general problems concerning cumulus clouds in a review article by Malkus (1952a).

In this paper the data are merely presented case by case with a minimum of interpretative discussion. The study of individual clouds is subordinated to an emphasis on the over-all flow picture and the effects of the island thereupon. Much of the information is given in tabular form. In this way it is hoped to be most useful for the many possible studies which may be made concerning the modification of a stable air stream by a heated land mass.

Altogether eight individual case studies were made during the summer of 1950. Case 1 was made over an area different from those remaining and a paper on it has been published elsewhere (Malkus, Bunker, and McCasland, 1951). Among 2-8, five cases of varying degrees of cumulus production were studied, and in contrast two days in which no convective clouds appeared. On two cases, fog eventually covered Nantucket. In every case, the incoming solar radiation varied little from the typical insolation curve shown in Figure 2. Presentation of each of the seven cases follows after a brief discussion of the observational procedures and instruments used.

[1] The work described in this paper was carried out as part of a research project conducted under Contract N6onr-27702 (NR-082-021) between the U. S. Navy's Office of Naval Research and the Woods Hole Oceanographic Institution.

[2] Observational studies of convection. Woods Hole Oceanographic Institution, Reference No. 49-51. Manuscript report to Office of Naval Research. 1949.

[3] The flow of a stable atmosphere over a heated island. Res. Rep. Dept. Physics, Illinois Inst. of Tech. 1951. Air flow over a heated island (II). Woods Hole Oceanographic Institution, Reference No. 52-27. 1952. Manuscript reports to Office of Naval Research.

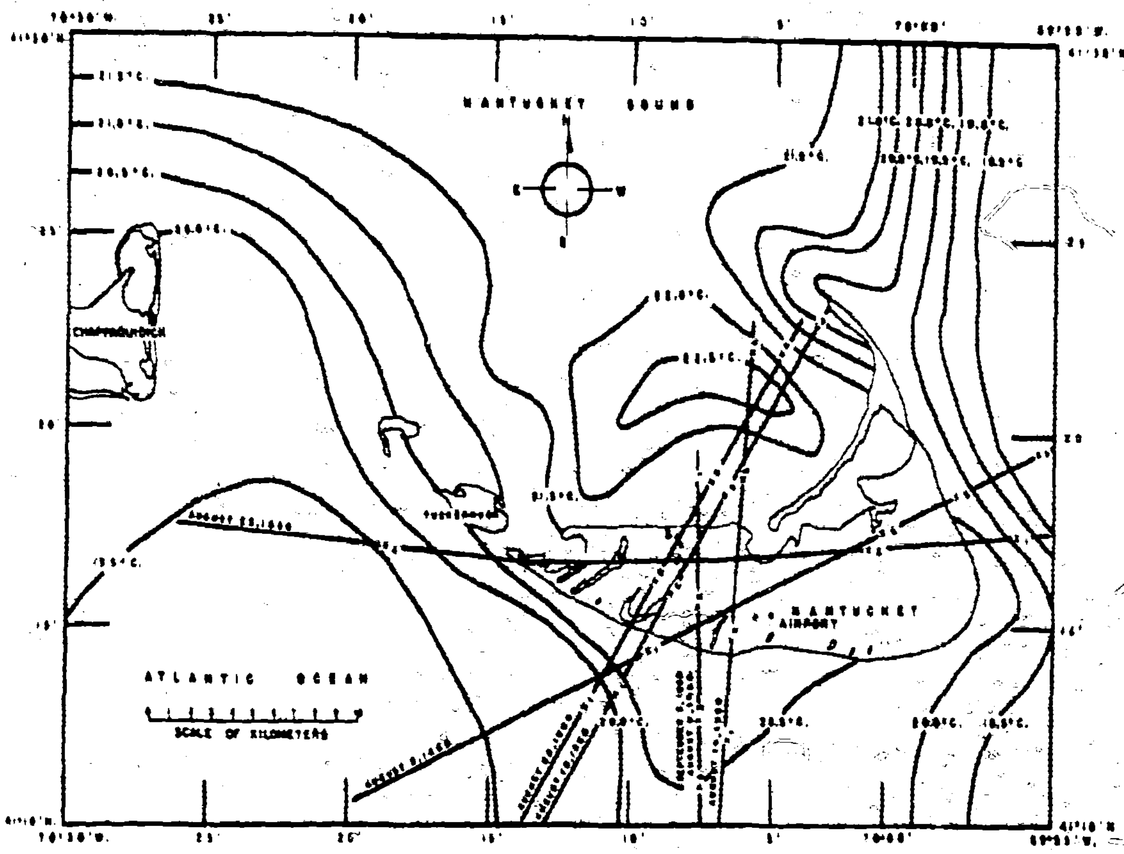

FIG. 1. Map of Nantucket Island showing the surrounding water temperatures and the cross sections flown by the observing plane. The temperatures were measured by means of a dip bucket thermometer on August 25, 1950. On the cross sections the central position of each helical sounding is indicated by a numbered cross. The horizontal runs were, in general, flown along the same line, in each case parallel to the surface wind direction.

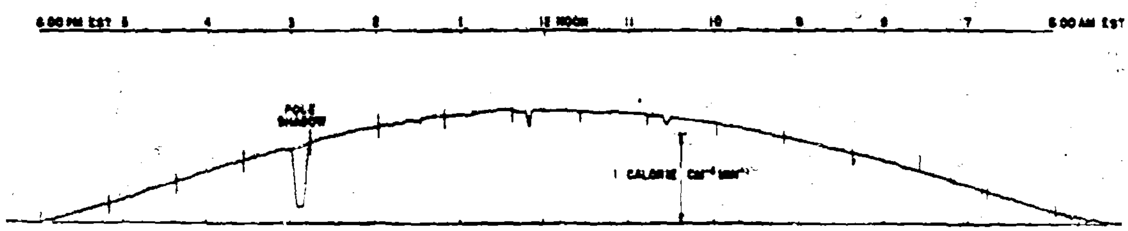

FIG. 2. Insolation curve as recorded by the pyrheliometer at Woods Hole. This curve was obtained on August 15, 1950. The insolation on most of the other days studied showed little deviation from this picture, except for short dips due to the passage of cumulus clouds.

II. OBSERVATIONAL PROCEDURES AND TECHNIQUES

A. Basic Observational Procedure

The observational program was centered around airplane measurements of temperature, moisture, and turbulence. The flights were oriented so as to obtain a cross section of the atmosphere across the island parallel to the wind direction. Two different flight patterns were executed: one a series of four helical soundings, the other a series of horizontal flights over the island and surrounding waters. The center position of each of the helical soundings flown is marked on the water temperature chart, Figure 1. The first helix was flown about 3 km upwind of the island, the second over the island, while the third and fourth were flown about 4 and 8 km downwind. On three of the cases (as indicated in the tables) an exacting routine was followed so that 400 ft. of altitude was gained with each revolution of the plane in the helix. The air speed was adjusted so that the helix diameter was 1.6 km. By marking on the records the exact moment of arrival at the upwind and downwind point of the helix, the exact position of the observation point could be obtained. The net result of this procedure was to obtain observations in eight well-defined vertical columns rather than in four mean position columns (as was the situation in the remaining cases). The horizontal runs over the island were flown upwind and downwind at several altitudes depending on the cloud base height. Notes were made of the plane's position, altitude, and air speed.

Numerous other observations were made to supplement the airplane flights, among the most important being those from observing stations on Tuckernuck Island and Nantucket Airport. The techniques, instruments, and observers are listed in the following paragraphs.

B. Observational Techniques, Instruments, and Observers

The following is a complete list of all observations taken and used in the present investigation and the instruments with which they were made. The observers or organizations taking the observations are stated. Weather Bureau observations were copied either from the original forms at the Nantucket Station or from the Daily Upper Air Bulletin of the U. S. Navy Weather Central.

1. *Airplane observations.* Dry- and wet-bulb temperatures, heights, vertical accelerations of the airplane, cloud photographs, and general notes were taken by either Joanne Malkus or Kenneth McCasland.

The airplane psychrograph is described in detail elsewhere by McCasland (1951).[4] Likewise the accelerometer has been reported on by Vine.[5] The plane's altimeter furnished the pressure-height readings. A simple arrangement of relays permitted the simultaneous side-marking of the temperature and accelerometer traces. A Speed Graphic camera loaded with plus-x film and equipped with a red filter was carried in the plane for cloud photographs.

2. *Nantucket airport observations.* Heat flow values were obtained at 2 m over the grass at the airport by Donald Parson, Jr. The routine pilot balloon, radiosonde, and surface observations of the U. S. Weather Bureau were used. The heat flow equipment has been reported on by Parson and Bunker (1952). It is sufficient to say that it is a recording computer that yields the heat flow through the air by forming the product of the instantaneous vertical component of the turbulent air by the instantaneous value of the temperature.

3. *Tuckernuck Island observations.* Pilot balloon, surface dry- and wet-bulb temperature, surface wind, sea temperature and cloud observations were made by Andrew F. Bunker. Time-lapse movies of the clouds forming over Nantucket were taken from this island, and some still pictures.

The pilot balloon observations made on Tuckernuck were taken in the usual manner with the standard equipment. The only deviation from the orthodox procedure was that the rate of ascent was decreased and 30-second readings were made

[4] Modifications of the airplane psychrograph and adaptation of the humidity strip to airplane soundings. Woods Hole Oceanographic Institution, Reference No. 51–59. Manuscript report to Office of Naval Research. 1951.

[5] "Accelerometer for Air Turbulence Measurements" by Allyn C. Vine. Memorandum on file at the Woods Hole Oceanographic Institution, August 1945.

to achieve more detailed information about the wind structure. A sling psychrometer, a Casella anemometer, and a dip bucket thermometer were used for the surface observations. The time-lapse pictures of the clouds were photographed with a Bolex 16 mm camera. A solenoid and timing device operated by batteries tripped the shutter so that pictures could be obtained at any interval from ½ second to 10 seconds. The Tuckernuck still photographs were taken by a 35 mm motor-driven Leica.

4. *Supplementary observations.* The temperature of the water surrounding Nantucket (results shown in Figure 1) was determined by Columbus O'D. Iselin, Jr. and David M. Owen. Both dip bucket and bathythermograph observations were obtained during a boat trip around the island. The bathythermograph has been described by Spilhaus (1938). Insolation was measured by the pyrheliometer mounted on the roof of the Oceanographic Institution building at Woods Hole. The instrument was constructed by the Eppley Laboratories and the readings were recorded on a Leeds and Northrup potentiometer.

C. Reduction of Data and Definition of Turbulence Index

A detailed discussion of the routine reduction of the potentiometer readings to the usual meteorological quantities such as dry-bulb temperatures, mixing ratio, and potential temperature will not be given. These computations were carried out with the aid of routine calibration tables, nomograms, and moisture charts.

A correction was made for the dynamic heating of the air as it is brought to rest at the thermistor, using the air speed of the plane and the experimentally determined factor 0.9 in the expression $0.9(v/100)^2$, where v is the air speed of the plane in miles per hour. This term gives the necessary dry-bulb correction in °C. The wet-bulb correction is found by multiplying this value by the ratio of saturation-adiabatic lapse rate to the dry-adiabatic lapse rate.

All other computations such as the pilot balloon observations were made in the standard manner.

One non-standard quantity, the turbulence index, has been used extensively in this paper and requires a definition and description of the method of determining it. The turbulence index is defined as the area enclosed by the envelope surrounding a 10-second trace of the vertical accelerations experienced by the airplane. The envelope is formed by connecting all the crests and then all of the troughs of the 10-second trace. A polar planimeter is used to measure the enclosed area. The turbulence index units are expressed in terms of the smallest subdivision of the planimeter. An intensity of the air turbulence which produces alternately, positive and negative accelerations of 100 cm sec^{-2} has a turbulence index of 24. It will be noted that the turbulence index has the dimensions of velocity; it is the product of an acceleration times a time. The velocity has no exact meaning, but serves very well as a measure of the turbulence of the air.

III. DISCUSSION OF INDIVIDUAL CASES

A. Case 2 — August 8, 1950, in which well-developed cumulus streets were formed.

The synoptic chart showed that the Nantucket area was in the northern portion of a high-pressure cell following the passage of a polar front nearly five days previously. During the early part of the day, the rear side of a small trough indenting the high was over the region, so that the lower level wind was weakly from the north. As the day passed, the small trough moved off to the east and the wind became the strengthening southwesterly associated with the western portion of the high.

During most of the time that the plane was observing, the surface wind remained northerly and only during the last horizontal traverses through and near the cumulus clouds, had it shifted to the south. The Tuckernuck pilot balloon observation at 1138 EST, in the middle of

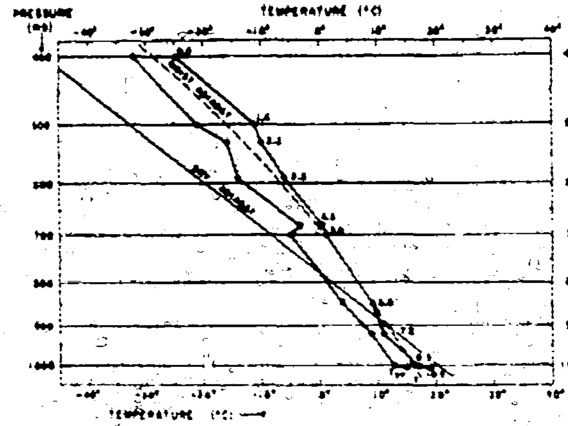

FIG. 3. Nantucket radiosonde observation, 1000 EST, August 8, 1950 (Case 2). The curve marked T is the temperature; that marked T_d is the dew-point temperature. The figures to the right of the temperature curve are mixing ratios in gm/kg. A dry adiabat is shown by the light solid line, and a moist adiabat by the light dashed line.

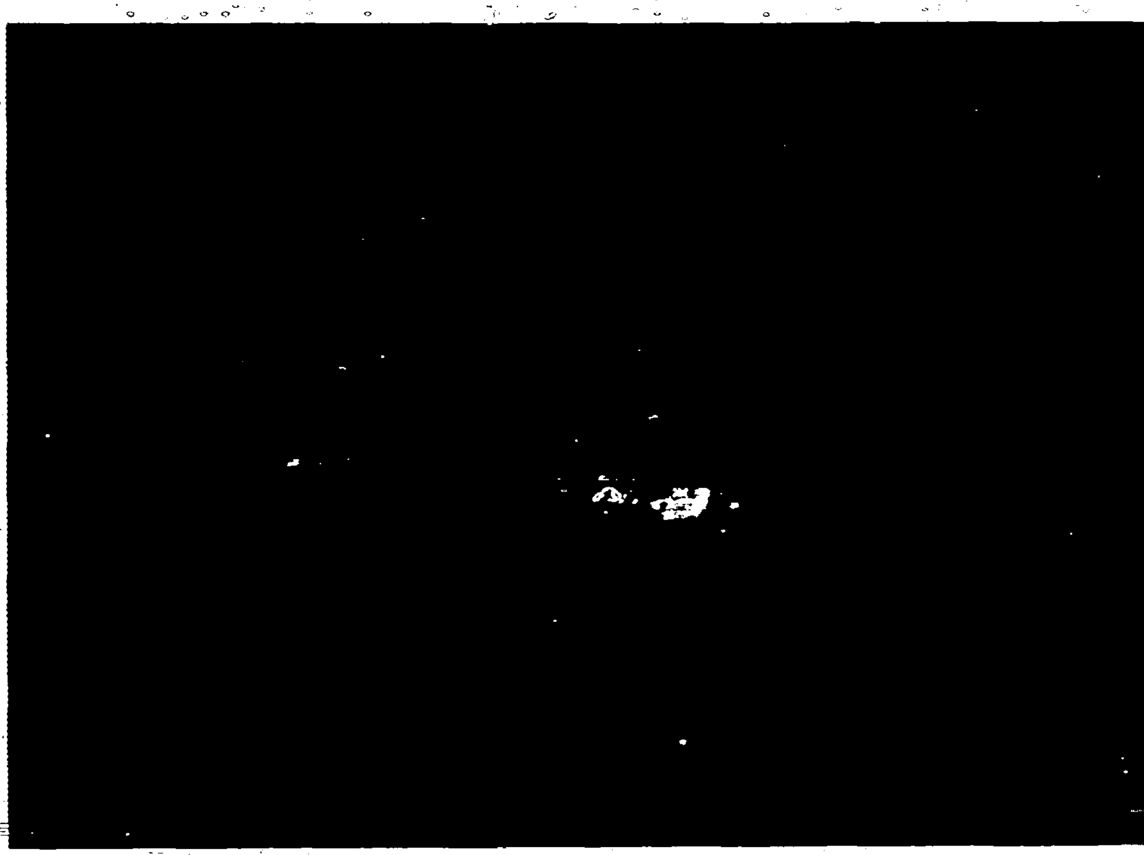

FIG. 4. Aerial photograph at 1215 EST, August 8, 1950, looking westward from Nantucket toward Marthas Vineyard. Land mass in foreground is Chappaquiddick Island (see Fig. 1). Clouds to far right are formed by Cape Cod.

FIG. 5. Aerial photograph at 1430 EST, August 8, 1950. The small island forming the cloud street is Tuckernuck, only 2 km in width. The clouds to the far right are formed by Chappaquiddick (see Fig. 4).

the observing period, showed a northerly surface wind of 1.8 mps, increasing to 4.8 mps at 1260 m (see Figure 6 and Table 1).

The sky was clear, with scattered cirrus and excellent visibility. The pyrheliometer record at Woods Hole showed a maximum insolation rate of 1.4 gm cal/cm² per minute. Upwind of the island the low-level air temperature was a little more than 2°C colder than the water temperature of 20.6°C.

The Nantucket radiosonde, reproduced in Figure 3, showed the effects of heating from below by a strong lapse rate in the first 1 km, which was, except for the superadiabatic lowest 50 m, 0.85°C/100 m. From 1 km to 1500 m, the air was more stable, the lapse rate being 0.3°C/100 m. Above 1500 m it steepened slightly and no inversions or marked stable layers occurred up to the highest level recorded at 400 mb. The mean mixing ratio from the surface to 800 m was about 8.5 gm/kg; in the cloud layer (800–1500 m) it was 7.1 gm/kg, and had fallen to 5.5 gm/kg at 2 km.

Early in the day, at about 0800 EST, cumulus streets began appearing downwind of the larger Cape Cod islands, being well-developed over even the smaller ones such as Tuckernuck by 1000 EST Some aerial photographs of these clouds are shown in Figures 4 and 5. The airplane soundings were made in a north-south direction across Nantucket, along the line indicated in Figure 1. Unfortunately, these psychrograph records were insufficiently reliable to reproduce, but by the time of the horizontal traverses at 1345 EST the instruments were again operating properly. Figure 6 shows a cross section of the air over the island constructed from the horizontal runs at 60 m, 150 m, and 300 m, together with the turbulence index up to greater heights obtained from the accelerometer records made during the spiral

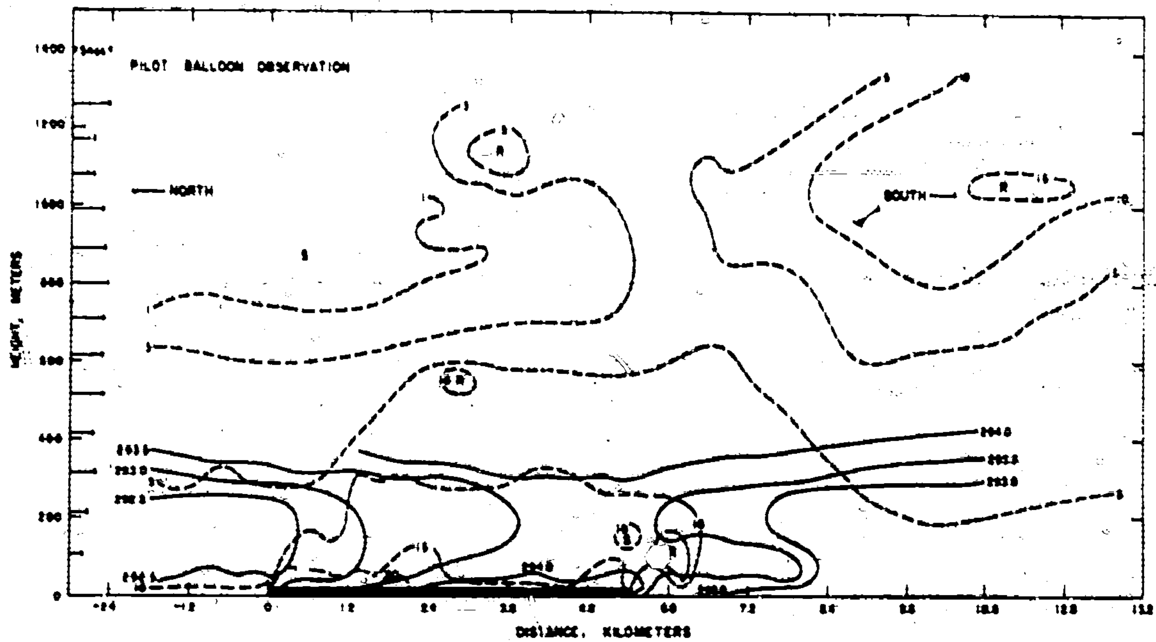

FIG. 6. Cross section made from horizontal traverses and soundings, Case 2, August 8, 1950. The potential temperatures in degrees absolute were obtained from horizontal flights at 60 m, 150 m, and 300 m between 1345–1435 EST and are shown by solid lines. The dashed lines are isopleths of turbulence index, in units equal to one planimeter division (see Section II C for definition and discussion of turbulence index). R stands for rough and is placed in areas of maximum turbulence index. S stands for smooth and is placed in areas of minimum turbulence index. The turbulence index above 300 m was obtained from the spiral soundings made between 1215–1345 EST. The wind component along the cross section is shown at the far left, as calculated from the 1138 Tuckernuck pilot balloon observation (see Table 1). The dark strip along the bottom (0–5.6 km) indicates the island. The horizontal distance scale originates at the upwind beach, so that distances are given in km downwind of this point.

soundings. Evidence of heating by the island is very pronounced at 300 m. From the vertical extent of the roughened air, together with the temperature gradient along the ground, it is plausible to infer that a well-mixed ground layer extended up to 700–800 m (see Cases 3 and 4). The forward-slanting roughened region extending well downwind of the island and to heights exceeding 1200 m is a result of the clouds' shooting repeatedly up into this area.

Cloud base was at 750 m upon the plane's arrival, rising to 850 m by midafternoon, and was always lower toward the eastern portions of the island. The highest cloud towers reached about 1500 m. Considerable information was obtainable from the photographs taken on this day. Figure 7 shows a section from the time-lapse films at about noon. The frames are reproduced every 30 seconds. Figure 8 shows a still picture taken at nearly the same time, which gives the orientation of the clouds with respect to the lee shore of the island. The low cliffs marking this shore appear just right of the center of the still photograph, and slightly to its left five radio towers are detectable. These were also detectable on the motion picture frames. The greatest rate of rise of the cloud towers shown in the motion picture strip occurred just over this spot. The cloud tower which goes through its active growth from the 2nd to the 10th frame (4 minutes) had an average rate of rise of 4 mps, which was calculated from the film since the location and height of the cloud were known. A second cloud repeats the cycle in the same spot from the 9th to the 17th frame, and following that a third one beginning in the 14th frame, indicating that this spot was probably a preferred location for the formation of cloud-scale updrafts. Another such location was evident just inside the lee shore and an even more pronounced region about 1 to 2 km off the lee shore. The large cloud towers were approximately 1.5 km apart. Further calculations from these photographs have been made and discussed by Malkus (1952). Several horizontal plane traverses were made through and near the clouds, but these were not begun until 1436 EST. By this time the clouds were dying

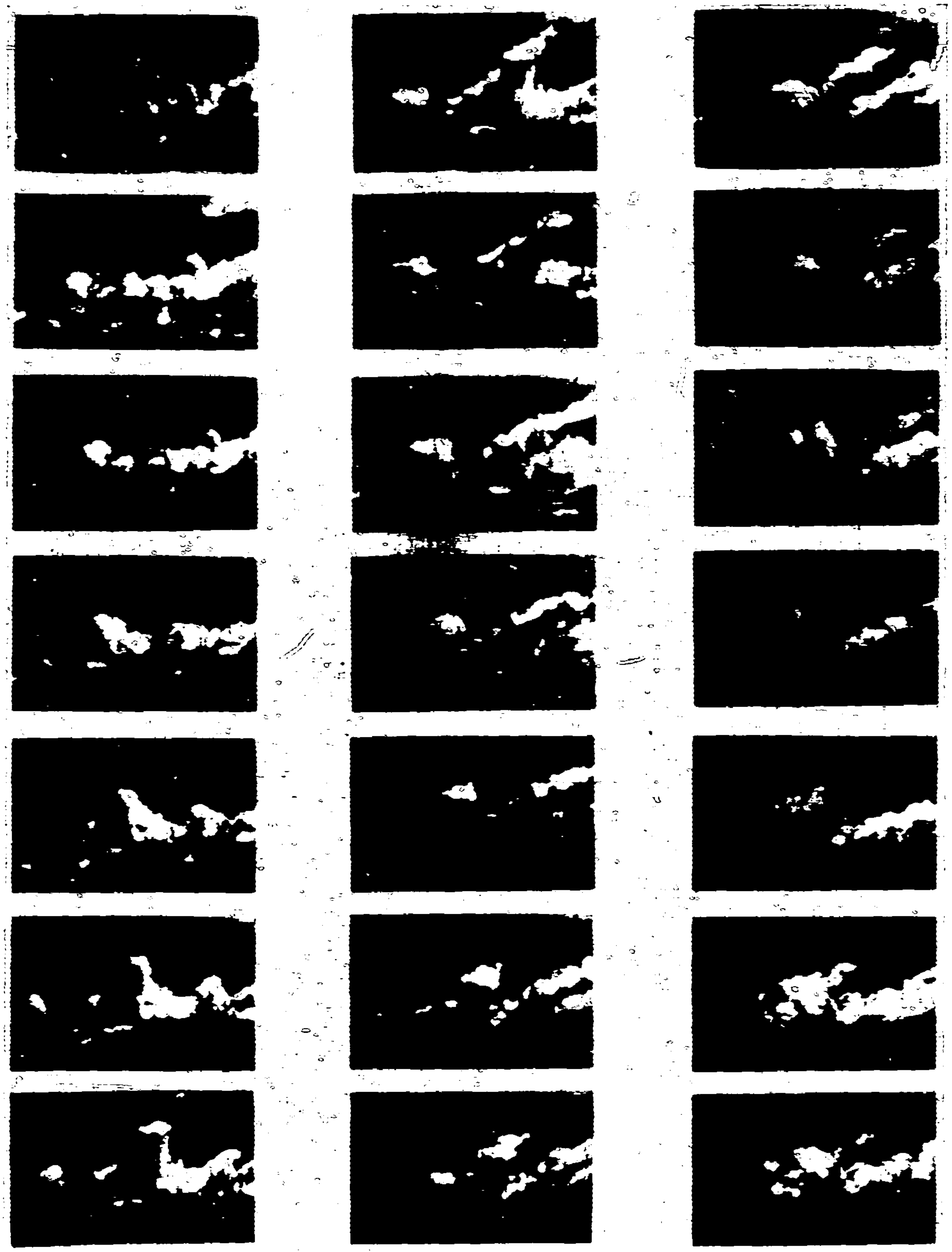

FIG. 7. Time-lapse pictures made of clouds over and near lee shore of Nantucket near noon August 8, 1950. Frames reproduced every 30 seconds. Camera located on Tuckernuck and pointed south of east. North is to the left and south to the right. The wind blows from left to right and increases slightly with elevation.

FIG. 8. Still picture taken from Tuckernuck at nearly the same time as the motion pictures of Fig. 7. Camera pointed just slightly south of east. The low cliffs just to the right of the center are the lee (south) shore of Nantucket.

and the low-level wind had become southerly. So little difference appeared between the clouds and their surroundings that these data have not been reproduced.

TABLE 4 — CASE 2

PILOT BALLOON OBSERVATIONS AT TUCKERNUCK ISLAND
AUGUST 8, 1950

1320 EST

Height (meters)	Direction (degrees clockwise from N)	Speed (mps)
108	010	2.6
216	035	3.0
315	331	3.0
414	331	1.8
513	333	2.5
612	355	2.7
707	005	3.5
801	015	4.3
890	003	4.9
990	002	6.3
1080	350	6.3
lost in cloud		

1130 EST

(9/10 cu diminishing to 5/10. Visibility excellent)

Height (meters)	Direction (degrees clockwise from N)	Speed (mps)
108	008	1.8
216	343	2.4
315	332	3.6
414	331	3.4
513	338	4.5
612	338	4.4
707	333	4.2
801	346	5.2
890	353	4.6
990	010	4.2
1080	030	4.0
1170	026	3.6
1260	012	4.8
lost in cloud		

Table 2 — Case 2

Surface Observations at Tuckernuck Island
August 8, 1950

Time (EST)	Td °C	Tw °C	Direction (degrees clockwise from N) (estimated)	Speed (mps)	Clouds (cumulus)
1230	20.3	16.5			None overhead
1330	20.4	15.6	270	2–5	1/10. {2/10 around horizon}
1430	20.4	17.0	180	2–5	3/10
1530	20.8	17.7	260	5–10	On horizon

Water temperature off south beach (1230) 20.6°C.

Table 3 — Case 2

Insolation as Given by Pyrheliometer at Woods Hole
August 8, 1950

Hour (EST)	Insolation (gm cal/cm² hours)	Hour (EST)	Insolation (gm cal/cm² hours)
0808–0908	36.0	1208–1308	74.0
0908–1008	46.5	1308–1408	75.0
1008–1108	60.5	1408–1508	74.0
1108–1208	63.5	1508–1608	52.5

Table 4 — Case 2

Pilot Balloon Observations at Nantucket Airport
August 8, 1950

Height (meters)	Direction (degrees clockwise from N)	Speed (mps)
	1000 EST	
0	30	4.6
305	20	5.7
610	10	6.7
914	360	7.7
1219	360	7.7
1524	360	7.2
1829	360	6.7
2134	350	6.7
2438	340	5.7
	1600 EST	
0	230	5.7
305	240	3.1
610	300	3.1
914	330	7.2
1219	330	10.3
1524	340	12.4
1829	350	12.4
2134	350	12.4
2438	350	10.8
2743	350	9.8
3048	350	8.2

B. Case 3 — August 9, 1950, in which no cumulus clouds were formed.

The synoptic situation showed a new polar front appearing north of the area, cutting the Great Lakes and reaching into Labrador, with Nantucket located in another slight trough indenting the rear portion of the predominating high-pressure cell. This high was now becoming a warm anticyclone. The average gradient wind was from west southwest, and the air reaching Nantucket had a trajectory of about 150 miles over water which was cooling it from below. The day began clear, with visibility restricted by haze. At 0930 EST, some cirrus appeared, gradually increasing to a 7/10 coverage by 1330, at which time the haze had lowered the visibility from 3 to 2 miles.

The morning (1000 EST) Nantucket radiosonde flight, reproduced in Figure 9, showed a small inversion based at about 150 m and a larger

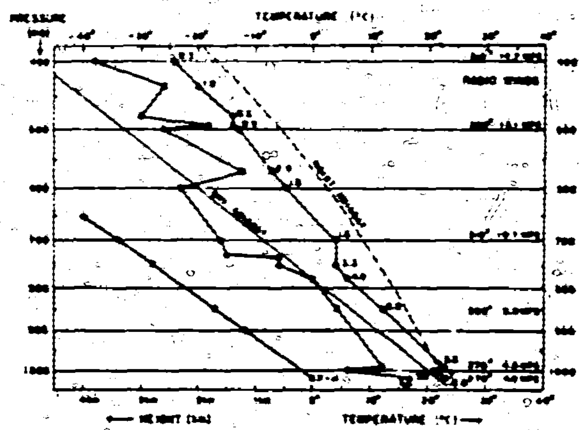

Fig. 9. Nantucket radiosonde observation, 1000 EST, August 9, 1950 (Case 3). The curve marked T is the temperature; that marked T_{DP} is the dew-point. The curve marked P–H is the pressure height curve. The figures just to the right of the temperature curve are mixing ratios in gm/kg. The radio-wind observations made at the same time are entered at the appropriate pressures at the extreme right.

one based at about 2.8 km. The mean mixing ratio in the lowest 2.8 km was 6.5 gm/kg, decreasing rapidly above. The direction of the airplane flights was along a line from west southwest to east northeast. The upwind (first) sounding showed a low-level inversion from the surface to about 150 m which was far stronger than that measured by the Nantucket radiosonde over the island. The lapse rate in this lowest layer was calculated to be −2.66°C/100 m. From 150–1200 m, the lapse rate was 0.62°C/100 m.

The pyrheliometer record at Woods Hole showed a maximum insolation rate at noon of about 1.2 gm cal/cm² min. Due to the advancing cirrus, the insolation rate declined more rapidly after noon than in the typical picture shown by Figure 2. Computation of the sensible heat accumulated between Sounding 1 (see Figure 1 for location), which was assumed representative of the air just off the upwind shore, and Sounding 2,

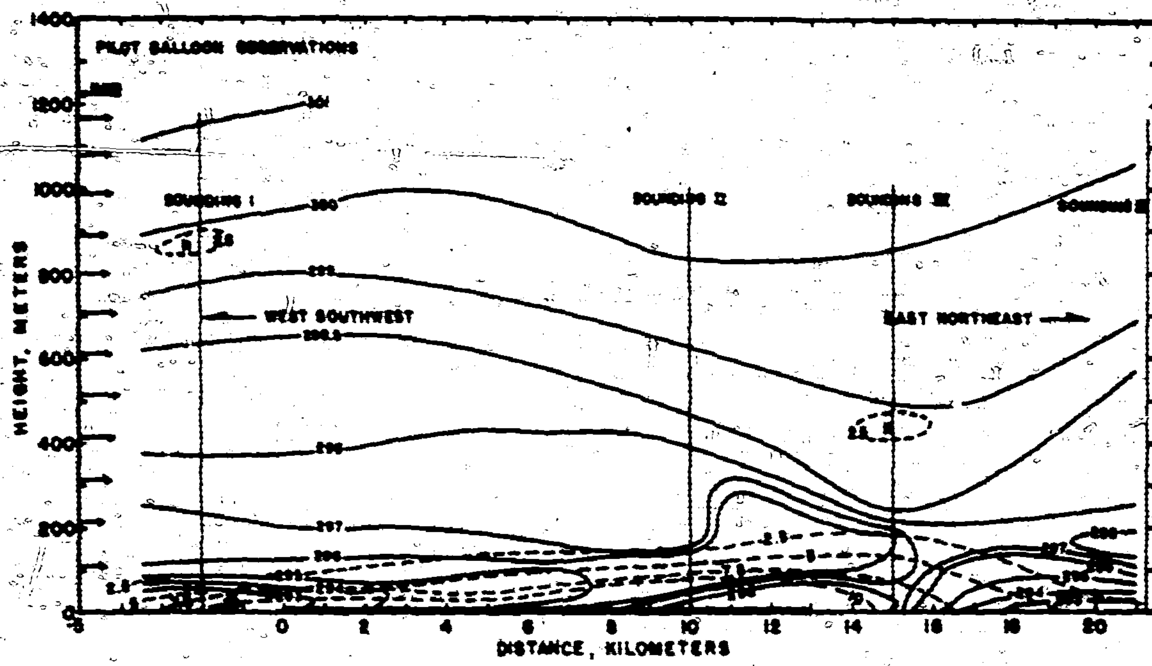

FIG. 10. Cross section made from airplane soundings, Case 3, August 9, 1950. The conventions are the same as those of Fig. 6. The soundings were made between 1050–1121 EST. The wind component along the cross section is shown at the far left, as calculated from the 1236 Tuckernuck pilot balloon observation (see Table 5).

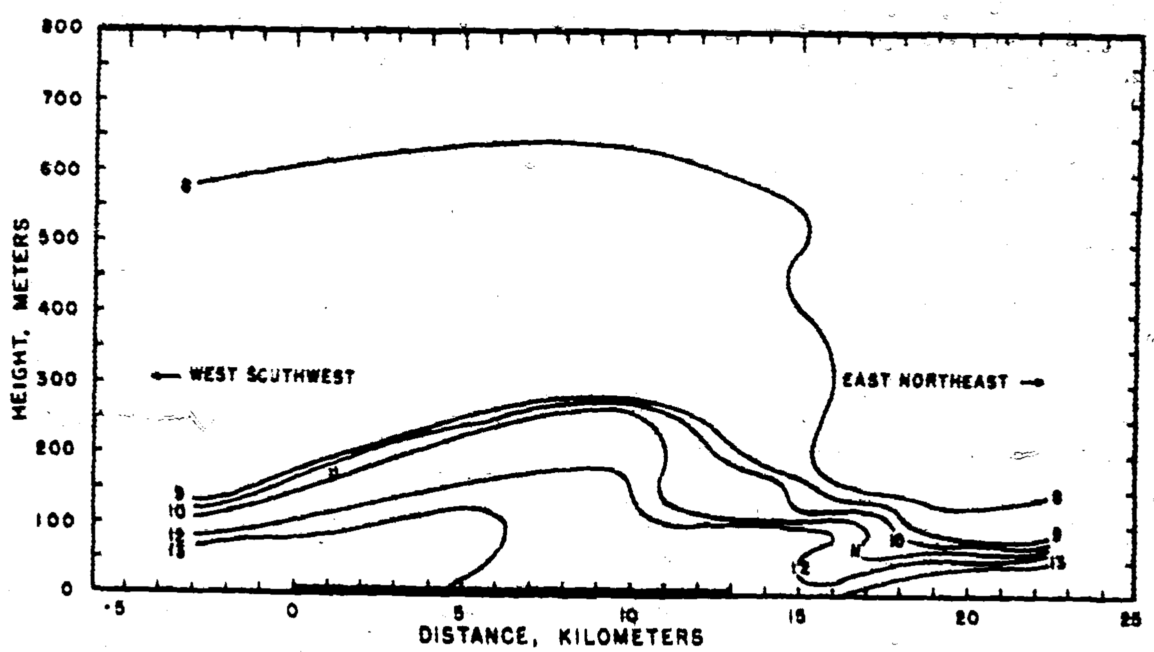

FIG. 11. Cross section of mixing ratio in gm/kg constructed from the same soundings as those of Fig. 10.

made centrally over the island, gave a result corresponding to a sensible heat flux into the air of 0.6 gm cal/cm^2 min. Comparison of these two soundings showed that the heating by the island was mainly confined to the lowest 150–200 m of air, although perceptible warming of the air was detectable up to 800 m on the second sounding. A measurement by the heat exchange computer (see Section II B) operated on Nantucket airport, just south of the location of Sounding 2 (see Figure 1 for location), showed a heating rate of only about 0.2 gm cal/cm² min. This instrument was operated somewhat later than the soundings, however, and meanwhile the cirrus cover had increased from 3/10 to 6/10. Between Sounding 2 and Sounding 3, which was made just off the downwind shore, sensible heat was still being accumulated by the air at a rate of nearly 0.4 gm cal/cm² min, while between Sounding 3 and Sounding 4, 6.5 km off the downwind shore, sensible heat was being removed from the air at a rate of nearly 1.0 gm cal/cm² min. This was ten times greater than the downwind rate of heat removal on any of the other Nantucket cases. Figure 1 shows that the very coldest water near Nantucket is found off the east shore where Sounding 4 was made. Furthermore, the shallow vertical penetration of the heating due to the high initial stability would facilitate relatively more rapid removal of the added heat than on a day when the island heating had been diffused through a thicker layer.

The 1236 EST Tuckernuck pilot balloon observation (Table 5) showed a mean wind in the lowest 1200 m which was west southwest about 10 mps, exhibiting only very slight turning toward the west with height. As indicated by the 1000 EST Nantucket radio wind observation (see Figure 9), this clockwise turning became more pronounced higher up, along with an increase in wind speed.

While several cumulus clouds were observed forming over Marthas Vineyard and over Cape Cod on the horizon, no cumulus at all were formed over Nantucket on this day. The results of the airplane soundings are shown in Figures 10 and 11. Figure 10 gives the distribution of potential temperature and turbulence index in a cross section parallel to the surface wind. The low maximum value of turbulence index over the island and the sharp confinement of the roughened air within the first 200 m over the island are particularly noteworthy. No large-scale redistribution of turbulence, heat or moisture occurred over Nantucket in this case. Figure 11 shows the simultaneous distribution of mixing ratio along the same cross section. Note that while the initial moisture stratification is modified somewhat by mixing over the island, a pronounced drying out and restratification occurs about 3 km beyond the downwind shore, probably indicating the presence of descending motion. The large-scale eddy exchange coefficient (Austausch) for sensible heat could be estimated from the heat accumulation from one airplane sounding to the next and the observed vertical gradient of potential temperature. Its value was largest in the lowest 150 m directly over the island where it averaged slightly less than 100 gm cm⁻¹ sec⁻¹. Elsewhere, fluxes and gradients were too small to permit an estimation. It is unlikely in such a stable air stream that turbulent fluxes were of significance away from the immediate vicinity of the island.

Table 5 — Case 3

Pilot Balloon Observation at Tuckernuck Island
1236 EST
August 9, 1950

Height (meters)	Direction (degrees clockwise from N)	Velocity (meters per sec.)
35	230	5.0
108	240	8.5
216	238	11.5
315	243	11.6
414	243	11.6
513	243	10.0
612	243	10.0
707	245	10.0
801	245	10.0
890	248	9.5
990	250	7.3
1080	255	6.7
1170	255	7.3

Table 6 — Case 3

Surface Observations at Tuckernuck Island
August 9, 1950

Time EST	Td °C	Tw °C	Low Cloud	Middle Cloud	High Cloud	Vis. (miles)	Wind Direction (estimated)	Speed mps
0930	20.2	19.9	—	—	1/10 ci	3	SW	10
1030	21.0	19.3	—	—	2/10 ci	3	SW	10
1130	21.6	19.6	1/10 cu on horizon	—	3/10 ci	3	SW	10
1230	22.2	20.0	—	—	6/10 ci	3	SW	10
1330	23.1	20.6	—	—	7/10 ci	2	SW	10

Water temperature off south beach (1145) 21.2°C

Table 7 — Case 3

Insolation as Given by Pyrheliometer at Woods Hole
August 9, 1950

Hour (EST)	Insolation (gm cal/cm² hour)	Hour (EST)	Insolation (gm cal/cm² hour)
0708–0808	36.0	1108–1208	70.5
0808–0908	49.0	1208–1308	65.5
0908–1008	58.5	1308–1408	59.0
1008–1108	71.0	1408–1508	52.5

CASE 3 — AUGUST 9, 1950

SOUNDING 1

Over water, 1.3 km upwind of windward shore 1008–1026 EST

Pressure mb	Height m	Temperature °C	Mixing Ratio gm/kg	Potential Temp. °K	Turbulence Index
1010	47	20.8	13.6	293.2	7
1009	63	20.9	13.6	293.5	4
1007	71	21.2	13.6	294.1	3
1007	79	21.0	12.9	294.0	3
1005	94	23.1	11.7	296.0	2
1005	102	23.5	11.6	296.4	2
1005	102	23.4	11.4	296.4	2
1003	110	23.8	11.1	296.7	2
1003	110	23.9	11.1	296.7	2
1001	125	24.3	10.5	297.4	1
1001	133	24.4	9.5	297.4	1
999	141	24.8	8.6	298.1	1
998	156	24.0	7.8	297.2	1
996	164	23.7	8.0	297.2	1
994	188	23.7	7.9	297.4	1
990	220	23.5	8.3	297.5	1
987	250	23.4	8.1	297.5	1
983	282	23.1	8.0	297.9	1
980	313	22.9	7.8	297.9	1
976	344	22.7	7.6	298.0	1
973	376	22.4	7.8	298.0	1
969	406	22.0	8.3	298.1	—
966	438	21.7	8.3	298.0	—
962	470	21.5	8.2	298.1	—
959	501	21.3	8.1	298.1	—
955	532	21.0	7.9	298.1	—
952	563	20.8	8.0	298.4	—
945	625	20.3	7.7	298.5	1
938	690	19.7	7.6	298.6	1
927	784	19.9	8.0	299.0	1
910	940	18.7	7.3	300.1	1
894	1100	18.0	7.3	300.9	—

CASE 3 — AUGUST 9, 1950

SOUNDING 2

Over island, 11.1 km downwind of windward shore

1035–1051 EST

Pressure mb	Height m	Temperature °C	Mixing Ratio gm/kg	Potential Temp. °K	Turbulence Index
1011	39	25.5	12.5	298.0	missing
1010	49	24.9	12.2	297.4	missing
1009	63	24.1	12.5	296.7	missing
1007	71	25.2	13.5	298.0	missing
1007	79	24.6	12.3	297.2	missing
1005	94	23.6	12.6	296.4	missing
1005	102	23.6	11.6	296.4	missing
1003	110	23.5	12.4	296.4	missing
1001	125	23.8	12.0	296.9	missing
998	156	23.8	9.3	297.1	missing
998	164	24.6	12.2	298.0	missing
996	172	24.4	11.8	298.0	missing
994	188	24.4	10.2	298.1	missing
992	214	24.0	13.5	298.0	missing
990	220	22.7	11.2	298.6	missing
990	228	23.8	10.7	297.9	missing
988	234	24.2	10.7	298.4	missing
988	242	23.4	13.2	297.9	missing
987	250	24.4	8.1	298.5	missing
987	262	23.0	11.0	297.4	missing
985	270	23.0	11.6	297.5	missing
985	278	23.2	8.6	297.6	missing
983	282	23.4	8.6	298.0	missing
983	290	24.2	8.5	298.7	missing
978	313	24.1	8.4	299.3	missing
978	321	23.3	8.6	298.5	missing

SOUNDING 2 — (continued)

Pressure mb	Height m	Temperature °C	Mixing Ratio gm/kg	Potential Temp. °K	Turbulence Index
977	337	23.8	8.5	298.9	missing
976	344	23.6	8.6	298.6	missing
973	376	23.1	8.7	298.6	missing
969	406	23.1	9.8	299.0	1
967	421	22.1	7.9	298.2	1
966	438	22.0	7.9	298.2	1
966	446	22.6	8.6	298.5	1
962	470	22.5	8.5	299.0	1
960	485	22.5	8.4	299.1	1
959	501	22.5	8.0	299.2	1
959	509	21.7	8.1	298.5	1
957	517	21.9	7.7	298.6	1
957	525	21.4	7.8	298.4	1
955	532	22.1	8.5	299.2	1
953	556	21.9	8.5	299.1	1
952	563	21.4	7.7	298.8	1
950	579	20.8	7.8	298.4	1
948	595	21.1	8.1	298.9	1
945	625	21.3	8.1	299.3	1
941	658	20.9	7.9	299.1	1
938	690	20.6	7.9	299.7	1
934	720	20.5	8.0	299.4	1
931	751	20.0	7.9	299.2	1
927	784	19.9	7.8	299.3	1
924	815	19.6	7.7	299.4	

CASE 3 — AUGUST 9, 1950

SOUNDING 3

Over water, 15.2 km downwind of windward shore

1055–1106 EST

Pressure mb	Height m	Temperature °C	Mixing Ratio gm/kg	Potential Temp. °K	Turbulence Index
1014	16	25.7	12.0	298.0	10
1013	23	25.6	11.6	298.0	10
1012	31	25.1	12.0	297.4	9
1009	63	25.0	12.3	297.5	8
1006	86	24.9	12.3	297.5	6
1005	94	24.1	10.3	297.0	6
1003	110	24.3	10.1	297.2	6
1001	125	24.2	9.6	297.3	6
999	140	23.6	9.8	296.8	6
998	156	23.7	10.8	296.9	6
997	172	23.5	8.6	297.0	2
994	188	23.9	7.9	297.5	2
992	198	23.6	7.9	297.3	2
990	220	24.4	8.6	298.4	1
987	250	24.9	8.6	299.1	1
983	282	24.4	8.7	299.0	1
980	313	23.9	8.6	298.6	1
976	344	23.7	8.4	298.9	1
973	376	23.7	8.1	299.1	1
969	406	23.4	8.2	299.2	2
966	438	23.0	7.6	299.0	3
962	470	22.2	7.6	298.6	2
959	501	22.6	8.1	299.1	1
955	532	22.1	8.4	299.2	1
953	548	21.2	7.7	298.6	1
952	563	21.3	8.2	298.6	1
950	579	21.6	7.9	299.0	1
948	595	21.5	7.9	299.1	1
945	625	21.4	7.9	299.4	1
941	658	21.1	7.0	299.3	—
939	673	20.5	7.1	299.1	—
938	690	21.0	7.5	299.5	—
931	751	20.5	7.6	299.8	1
927	784	20.1	7.8	299.5	1

Case 3 — August 9, 1950

Sounding 4

Over water, 19.8 km downwind of windward shore

1111–1121 EST

Pressure mb	Height m	Temperature °C	Mixing Ratio gm/kg	Potential Temp. °K	Turbulence Index
1015	8	19.8	13.8	292.0	4
1014	16	20.6	13.1	292.8	1
1013	23	20.5	13.5	292.8	1
1012	31	21.7	14.2	294.0	1
1010	47	22.5	13.8	295.0	1
1010	55	22.7	13.7	295.1	1
1009	63	23.4	10.3	296.1	1
1007	78	23.7	8.0	296.4	1
1005	94	24.9	8.6	297.5	1
1001	125	24.8	8.6	298.0	1
998	156	25.1	7.7	298.4	1
994	188	24.1	7.4	298.0	1
990	220	23.7	7.4	297.6	1
987	250	23.5	7.5	298.0	1
983	282	23.3	7.5	298.1	1
978	313	23.0	7.6	298.2	1
976	344	22.9	7.4	298.2	1
973	376	22.4	7.6	298.1	1
962	470	21.6	7.6	298.1	1
945	625	20.5	7.2	298.5	1

C. Case 4 — August 14, 1950, in which well-developed cumulus streets were formed.

The synoptic picture showed a polar front looping from the Great Lakes region southeastward through northern Florida and northeastward out into the Atlantic. A moderate cold high was centered in Pennsylvania. Nantucket was located in a small, weak trough indenting the forward portion of this high, so that although the gradient wind was weakly from the south, the air reaching the island had only a short trajectory over water. The trough was shallow, and the gradient wind very rapidly veered with height through west toward northwest. The visibility was good throughout the day, and the temperature of the lowest air upwind of the island was very nearly equal to that of the water. The most significant feature of the undisturbed current on this day was the fact that the flow over Nantucket was very weak from the south up to about 900 m, while above that, it was weakly from the north.

Fig. 12. Aerial photograph showing Tuckernuck cloud street, Case 4, August 14, 1950, made at 1025 EST.

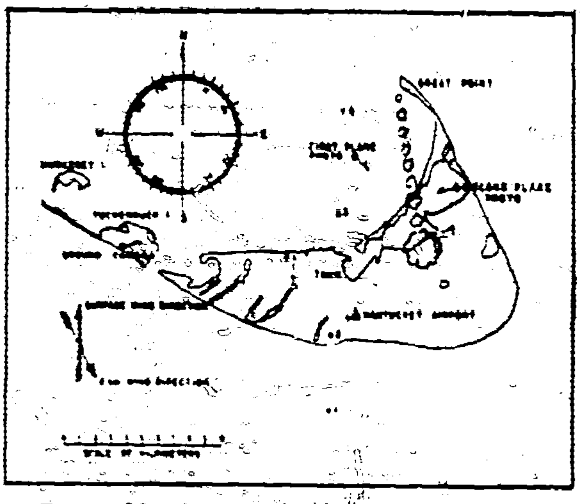

FIG. 13. Map showing major Nantucket cloud street, Case 4, August 14, 1950. Clouds are reconstructed in nearly exact location and to scale. Fig. 14 was taken from Tuckernuck Island (marked "ground camera"), while Figs. 16 and 17 were taken from the air at those places marked "first plane photo" and "second plane photo", respectively. The locations of the centers of the helical soundings are shown by the numbered crosses, and most of the horizontal runs were made along the same section.

Most of the cumulus clouds, however, terminated below or near the level of wind discontinuity, with only a few of the tallest towers shooting far above into the region of northerly winds. Nearly all the islands were forming cloud streets on this day, even including Tuckernuck which is less than 2 km wide. The first cumulus over Cape and islands were seen about 0830 EST. An aerial photo (Figure 12) looking west northwest from above the western portion of Nantucket toward Chappaquiddick Island shows the Tuckernuck clouds and the westernmost Nantucket sequence at 1025 EST. The Nantucket clouds formed into very clearly defined streets, with a large cloud over the island, and smaller, periodically-spaced puffs extending over a distance of about 10 km downwind. The location, approximate size, and spacing of the most striking cloud street studied are shown in Figure 13. This entire street was photographed from Tuckernuck at 1248 EST (Figure 14). Shortly after this photograph, the large cloud on the right shot up a tall, southward-

FIG. 14. Photograph from Tuckernuck Island looking east northeast toward Nantucket (see Fig. 13) showing major Nantucket cloud street at 1248 EST, August 14, 1950. Cloud base is at 450 m.

slanting tower, reaching up to about 2.1 km, which gradually increased its slant toward the south and decayed (see time-lapse strip, Figure 15). The main tower rose from a height of 850 m to

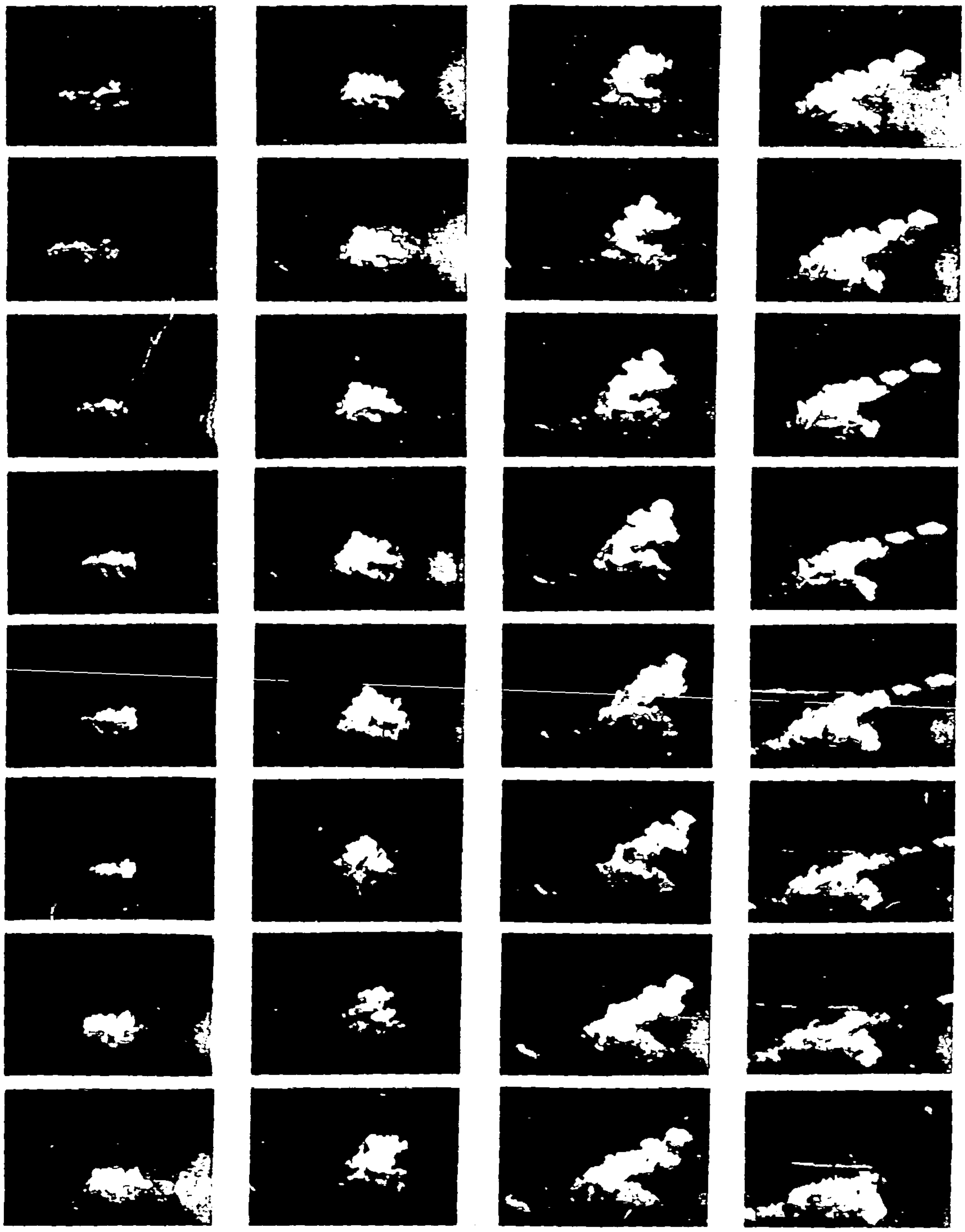

FIG. 14. Time lapse pictures of major Nantucket cloud street, August 14, 1952. Frames reproduced every half minute from 1245 EST to 1301 EST. Sequence begins at upper left. Time-lapse movie camera had same location and orientation as shown by the arrow marked "ground camera" in Fig. 13.

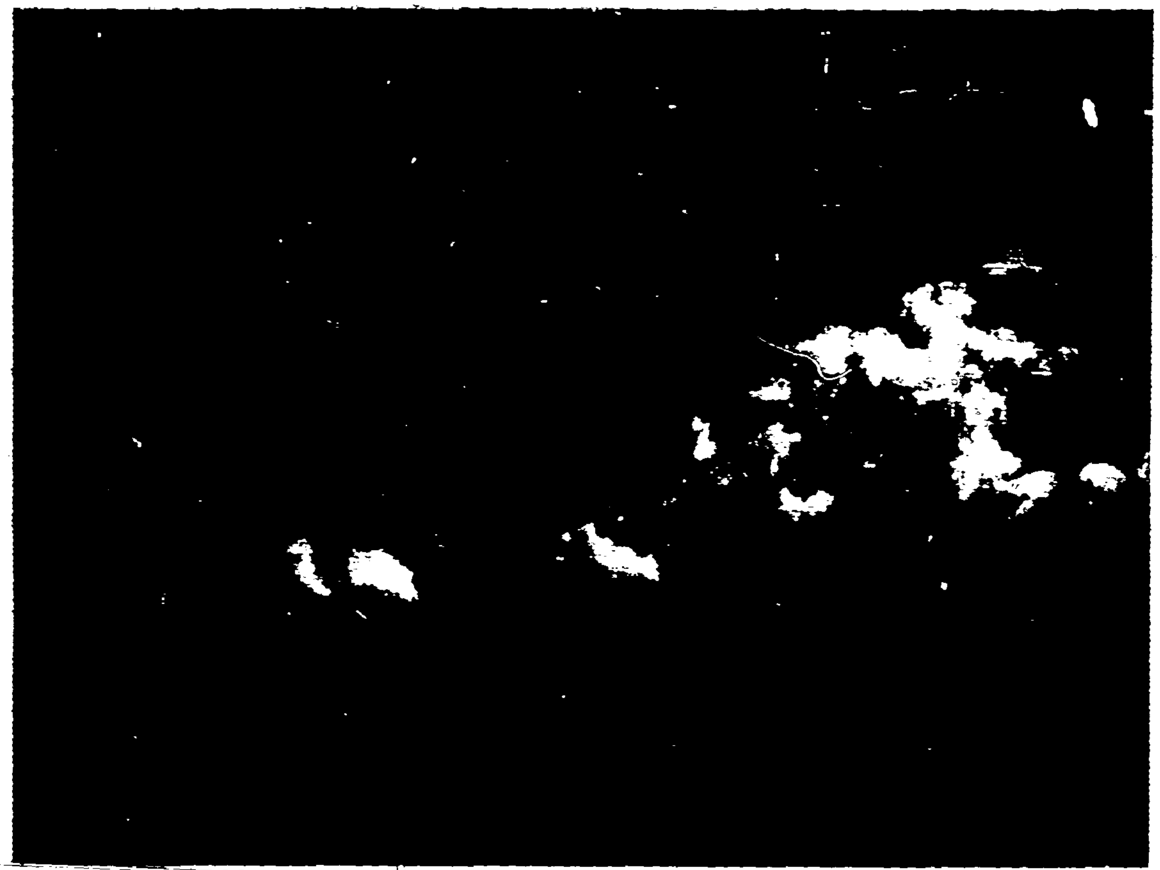

FIG. 16. Aerial photo of part of major Nantucket cloud street, August 14, 1950, from location marked "first plane photo" in Fig. 13. Taken between 1300 and 1310 EST.

2100 m in 10.5 minutes and the upper portions of the cloud descended again to about 1800 m in 4 minutes before dissipating. This would indicate mean ascending speeds of about 2 mps and mean descending speeds of just over 1 mps. The maximum vertical speed maintained over 30 seconds was an ascent rate of 5.2 mps exhibited briefly by a small portion of the tower. The maximum rate of descent during any 30-second period was 1.7 mps. These figures cannot be relied on to better than ±0.5 mps, and may, if anything, be slightly too large. The cloud spacing was readily calculated from Figure 14, since both the height of the cloud base, and the distance and orientation of the street with respect to the camera were accurately known. The distance between cloud centers came out to be just under 1 km. This figure was checked from Figure 12 by calculating the spacing of the cloud shadows which could be located accurately on a map of Nantucket. The same cloud street was also photographed from several angles by the observer in the plane (see Figures 16 and 17).

The Nantucket radiosonde observation at 1000 EST (Figure 18) showed rather low stability throughout, with a small inversion at 300 m and anothe only slightly stronger at 3.9 km. The mean mixing ratio up to the first inversion was 9.2 gm/kg, and from there up to 3.1 km was 4.9 gm/kg, dropping rapidly above. The upwind airplane sounding (see Figure 1) showed a mean lapse rate in the lowest 935 m (southerly flow) of 0.70°C/100 m, and from 935 m to the top of the sounding at 1255 m, a mean of 0.59°C/100 m.

The pyrheliometer record at Woods Hole showed a noon maximum insolation rate of 1.4 gm cal/cm² min. The amount of sensible heat accumulated between Sounding 1 and Sounding 2 corresponded to a heating rate of the air by the ground of 0.84 gm cal/cm² min. The heating effect of the island was noticeable as high as 1.1 km on this day. Between Sounding 2 and

FIG. 17. Aerial photo of part of major Nantucket cloud street, August 14, 1950, from location marked "second plane photo" in Fig. 13. Taken between 1300 and 1310 EST. Central cloud in photograph is third cloud from south end of street in Fig. 13.

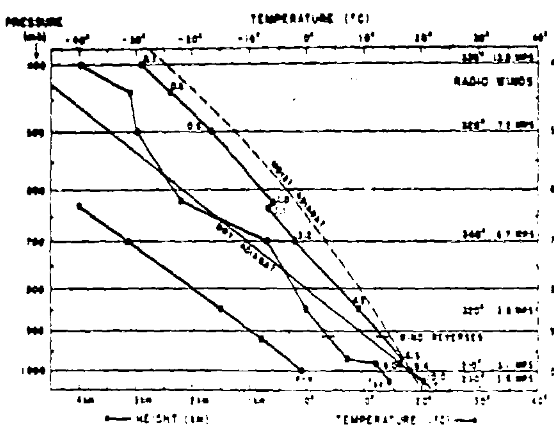

FIG. 18. Nantucket radiosonde observation, 1000 EST, August 14, 1950 (Case 4). Curve marked T is temperature; that marked T_{DP} is dew-point temperature. The curve marked P-H is the pressure-height curve. The figures to the right of the temperature curve are mixing ratios in gm/kg. The radio-wind observations made at the same time are entered at the appropriate pressures at the extreme right.

Sounding 3, sensible heat was accumulated by the air corresponding to a rate of 0.1 gm cal/cm² min, and between Soundings 3 and 4 heat was being removed at a rate corresponding to 0.07 gm cal/cm² min. The heat exchange computer, operated on Nantucket airport near noon showed a sensible heat flux of 0.47 gm cal/cm² min into the air.

The pilot balloon run made from Nantucket at 1000 EST (Table 8) and that made at Tuckernuck at 1337 EST (Table 9) both show very weak winds, with the shift from a southerly to a northerly component of flow taking place in the vicinity of 1 km. The Nantucket wind first backed then veered with height becoming northwesterly, while the Tuckernuck wind backed becoming northeasterly, the difference perhaps being attributable to a sea-breeze effect (causing outflow at several hundred meters from the largest part

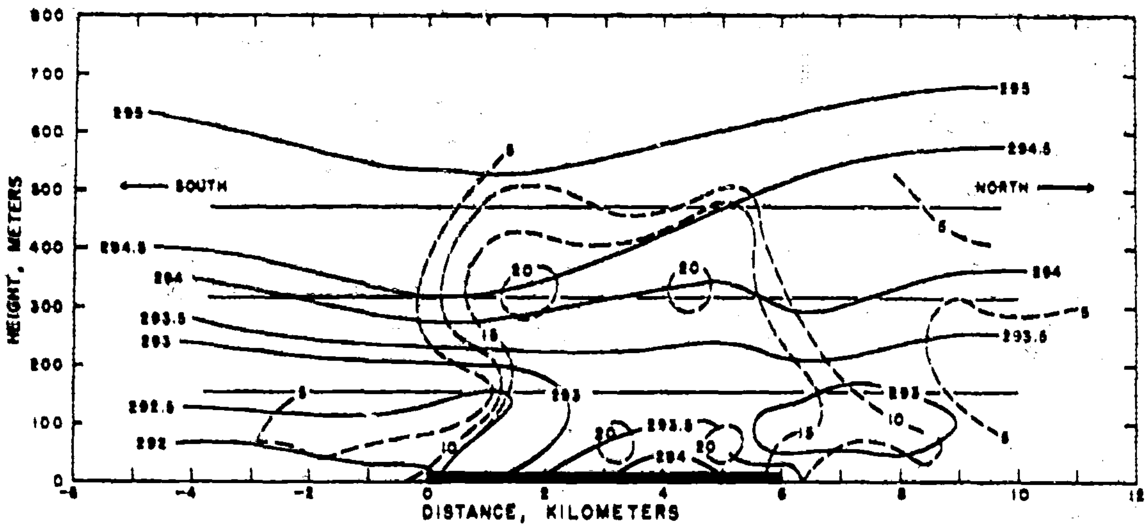

FIG. 19. Approximately north-south cross section constructed from horizontal airplane flights, 1205–1250 EST, August 14, 1950 (Case 4). Potential temperatures (solid lines) and turbulence index are shown. The units and conventions are the same as in the previous section (Fig. 10).

of the island). The average wind speed in the lowest 900 m (Nantucket observation, nearer the cloud street) was 1.2 mps.

Figure 19 was constructed from the horizontal airplane runs and gives an approximately north-south cross section of potential temperature and turbulence index during the period from 1205–1250 EST. Figures 20 and 21 were constructed from the airplane soundings which were made later, between 1315–1425 EST. Figure 20 again shows potential temperature and turbulence index, while Figure 21 shows the simultaneous distribution of mixing ratio. Note, in contrast with a case such as that of August 9 on which convection was weak or absent, the striking redistribution of moisture and potential temperature effected by the island. Also note the relatively high level to which roughened air extends. The mean eddy exchange coefficient for sensible heat in the lowest 300 m above the island was calculated from the accumulations shown by the soundings and the gradients in Figure 19. It was about 620 gm $cm^{-1} sec^{-1}$ in that region, and probably far smaller away from the island.

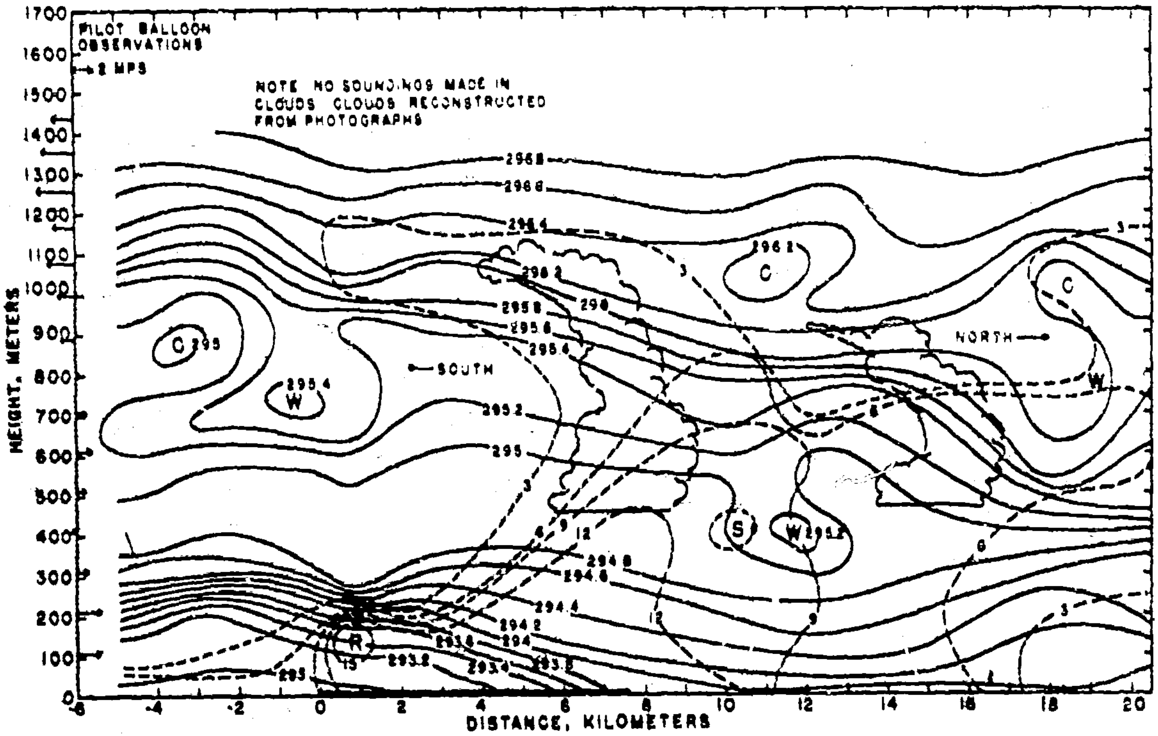

FIG. 20. Approximately north-south cross section constructed from the airplane soundings 1315–1435 EST, August 14, 1950 (Case 4) showing isopleths of potential temperature and turbulence index. The notation and units are the same as for the previous cross sections. C stands for potentially cool air and W for potentially warm. R stands for relatively rough air, S for relatively smooth. The clouds are not drawn in to scale, nor are they located exactly, but merely sketched to indicate the shape and vertical extent of the larger ones.

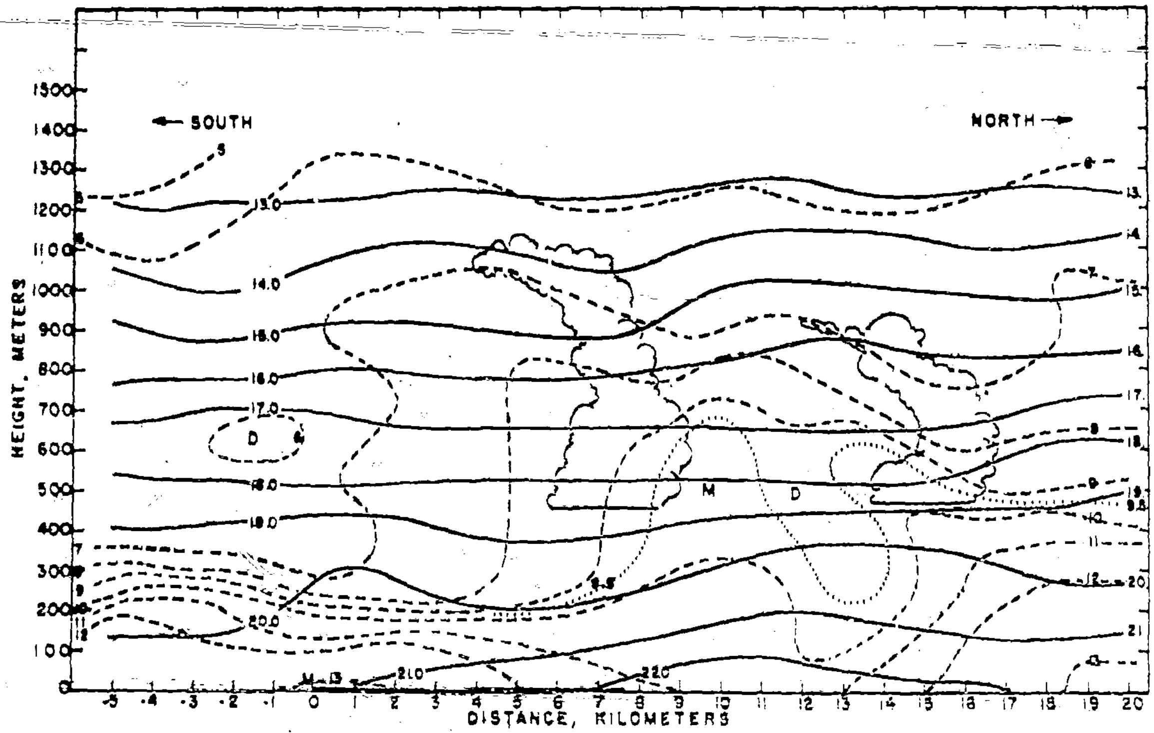

FIG. 21. Approximately north-south cross section constructed from the same soundings as Fig. 14, but showing temperature (solid lines, degrees centigrade) and mixing ratio (dashed lines gm/kg). M stands for relatively most air, D for relatively dry air.

FIG. 22. Aerial photograph of last remnants of Nantucket clouds, 1430 EST. Photograph taken from north of island (Just inside Great Point) looking south.

A slight weakening of convective activity during the hour between the horizontal runs and the soundings is apparent, as evidenced by a stabilization of the lapse rate over the island, and the diminished values of turbulence index. By the time of the last sounding, begun at 1410 EST, the airplane observer recorded the decay and disappearance of all but the larger clouds actually over the island (see Figure 22). While anvils were observed forming over Marthas Vineyard at noon, and thunderstorms took place over the mainland during the afternoon, none of the Nantucket clouds exceeded the swelling cumulus stage, and by 1445 EST had almost disappeared.

Fortunately on this day, some qualitative observations of the sea-breeze circulation were available. At about 1000 EST, the wind on both the south and north shores of Nantucket was from the south, but stronger on the south shore. At 1215, the plane observer recorded calm conditions on the north side. At 1500 EST, inflow toward the island center was occurring on both north and south sides, as noted by flow of smoke. Also, coincident with the decay of the cloud streets, a light inflow on the eastern shore was noted by the airplane observer.

Table 8 — Case 4

Pilot Balloon Observations at Nantucket Airport
1000 EST
August 14, 1950

Height (meters)	Direction (degrees clockwise from N)	Speed (mps)	Component along cloud street (mps) (positive from S)
0	230	3.6	1.3
305	190	3.1	3.0
610	180	1.3	1.2
915	230	0.9	0.3
1220	290	1.3	−1.9
1525	320	3.1	−2.9
1830	330	3.6	−3.5
2135	340	4.0	−4.0
2440	340	4.9	−4.9
2745	340	5.4	−5.4
3050	340	6.7	−6.7

Table 9 — Case 4

Pilot Balloon Observation at Tuckernuck Island
1337 EST
August 14, 1950

Height (meters)	Direction (degrees clockwise from N)	Speed (mps)	Component along cloud street (mps) (positive from S)
108	174	2.4	2.4
216	166	2.4	2.4
315	144	1.6	1.5
414	75	1.2	0
513	125	1.8	1.4
612	138	2.0	1.8
707	130	1.8	1.5
801	123	0.8	0.6
890	20	1.4	−1.1
990	21	2.0	−1.6
1080	09	2.6	−2.3
1170	10	2.2	−2.0
1260	15	4.0	−3.4
1350	13	3.4	−2.9
1440	33	3.2	−2.0
1530	08	1.8	−1.6
1620	29	4.0	−2.7
1710	24	3.0	−2.2
1800	05	3.6	−3.3
1890	353	4.0	−3.9
2070	354	4.2	−4.1

Table 10 — Case 4

Surface Observations at Tuckernuck Island
August 14, 1950

Time (EST)	Td °C	Tw °C	Direction (degrees clockwise from N)	Speed	Clouds
0950	20.4	18.4	200	0.7	3/10 cu
1045	21.8	19.2	190	0.1	3/10 cu
1145	23.5	20.0	210	0.3	3/10 cu
1245	22.6	19.6	210	0.3	4/10 cu
1400	23.4	19.6	190	1.0	2/10 cu
1445	22.9	19.5	190	0.8	2/10 cu

Water temperature (south beach) 21.6°C

Table 11 — Case 4

Hourly Insolation Rate at Woods Hole, August 14, 1950 as Measured by Pyrheliometer

Time (EST)	Insolation (gm cal/cm² hour)	Time (EST)	Insolation (gm cal/cm² hour)
0800–0900	60.11	1200–1300	70.13
0900–1000	76.14	1300–1400	20.[illegible]*
1000–1100	80.09	1400–1500	64.09
1100–1200	84.18	1500–1600	26.18

* Lowered due to passage of large cumulus or cumulonimbus cloud.

Case 4 — August 14, 1950

Sounding 1

Over water, 3.2 km upwind of windward shore 1315–1300 EST

Pressure mb	Height m	Temperature °C	Mixing Ratio gm/kg	Potential Temp. °K	Turbulence Index
1015	31 U*	20.8	12.6	293.0	7
1012	62 D	20.5	12.4	293.0	3
1004	126 U	20.0	12.5	293.0	5
997	188 D	19.7	11.6	293.1	2
990	250 U	19.7	9.6	294.0	2
983	313 D	19.6	7.8	294.5	3
976	376 U	19.3	6.6	294.9	1
969	438 D	18.8	6.7	294.9	1
962	501 U	18.3	6.4	295.0	2
955	563 D	17.7	6.2	295.0	2
948	625 U	17.3	6.4	295.3	2
941	690 D	17.0	6.2	295.5	1
934	75[illegible] U	16.2	6.6	295.2	1
927	815 D	15.6	6.7	295.1	2
920	870 U	15.1	6.6	295.1	2
914	935 D	14.6	6.5	295.0	2
907	1000 U	14.2	6.6	295.3	2
900	1065 D	13.7	6.5	295.5	1
893	1125 U†	13.6	5.9	296.1	1
887	1190 D	13.3	5.6	296.4	1
881	1255 U	12.7	4.9	296.4	2

* U represents upwind side of helix, D downwind side. Sounding flown according to exacting routine described in Section II A.
† Level of top of all but highest clouds.

Case 4 — August 14, 1950

Sounding 2

Over Nantucket, 0.6 km downwind of windward beach
1330–1350 EST

Pressure mb	Height m	Temperature °C	Mixing Ratio gm/kg	Potential Temp. °K	Turbulence Index
1015	31 U*	20.9	13.0	293.0	17
1008	95 D	20.7	12.5	293.2	16
1001	155 U	20.3	10.7	293.5	13
993	220 D	20.1	8.0	294.0	1
986	280 U	20.3	7.0	294.9	3
979	345 D	19.7	7.2	294.8	2
972	405 U	19.3	6.7	295.0	2
965	470 D	18.6	7.3	295.0	2
958	530 U	17.9	7.0	295.0	2
951	600 D	17.4	7.2	295.0	1
944	660 U	17.1	6.1	295.5	2
937	720 D	16.4	7.0	295.2	2
930	785 U	16.1	6.8	295.5	1
924	850 D	15.5	7.3	295.3	1
917	910 U	15.1	7.1	295.4	2
910	975 D	14.8	7.3	295.8	2
904	1040 U	14.7	6.8	296.2	3
900	1080 D	14.1	6.5	295.0	3
897	1100 D	14.1	6.5	296.2	3
890	1165 U	13.5	6.2	296.4	3
884	1225 D	13.1	6.1	296.5	3
877	1290 U	12.6	6.1	296.7	2

* U represents upwind side of helix. D downwind side. Sounding flown according to exacting routine described in Section II A.

Case 4 — August 14, 1950

Sounding 3

Over water, 8.3 km downwind of windward beach

1350–1405 EST

Pressure mb	Height m	Temperature °C	Mixing Ratio gm/kg	Potential Temp. °K	Turbulence Index
1015	31 U*	22.0	10.8	294.1	12
1008	95 D	21.8	10.1	294.5	8
1001	155 U	21.2	10.5	294.5	7
993	220 D	20.9	10.1	294.8	12
986	280 U	20.4	10.2	294.9	14
979	345 D	20.1	9.5	295.2	10
972	405 U	19.2	9.8	295.0	8
965	470 D	18.6	9.2	295.0	12
958	530 U	18.0	9.6	295.0	7
951	600 D	17.4	9.4	295.0	10
944	660 U	17.0	9.6	295.4	9
937	720 D	16.5	8.6	295.3	8
930	785 U	16.3	8.4	295.6	4
924	850 D	16.3	7.7	296.1	6
915	910 U	15.7	6.8	296.2	1
910	975 D	15.4	6.5	296.4	3
904	1040 U	14.9	6.2	296.2	2
897	1100 D	14.2	6.1	296.2	2
890	1165 U	13.8	6.3	296.5	2
884	1225 D	13.3	5.9	296.5	2
877	1290 U	12.8	5.8	296.8	1

* U represents upwind side of helix, D downwind side. Sounding down according to exacting routine described in Section II A.

Case 4 — August 14, 1950

Sounding 4

Over water, 14.2 km downwind of windward beach

1410–1425 EST

Pressure mb	Height m	Temperature °C	Mixing Ratio gm/kg	Potential Temp. °K	Turbulence Index
1015	31 U*	21.7	12.8	294.0	4
1008	95 D	21.5	12.9	294.1	3
1001	155 U	20.9	12.9	294.1	3
993	220 D	20.5	12.3	294.5	2
986	280 U	20.0	11.9	294.5	2
979	345 D	19.6	11.4	294.6	2
972	405 U	19.4	10.7	295.0	2
965	470 D	19.2	9.3	295.5	5
958	530 U	18.8	8.7	295.9	5
951	600 D	18.1	8.5	295.6	6
944	660 U	17.6	7.8	296.0	4
937	720 D	17.0	7.6	295.9	7
930	785 U	16.5	7.3	296.0	4
924	850 D	16.0	7.4	295.9	2
917	910 U	15.6	6.8	296.0	2
910	975 D	15.2	7.2	296.1	2
904	1040 U	14.6	7.0	296.0	3
897	1100 D	14.3	6.3	296.4	3
890	1165 U	13.8	6.1	296.5	3
884	1225 D	13.1	6.1	296.5	1
877	1290 U	12.7	6.0	296.7	1

* U represents upwind side of helix, D downwind side. Sounding down according to exacting routine described in Section II A.

D. Case 5 — August 15, 1950, in which there is an alternation between the formation and non-formation of cumulus clouds.

A high-pressure cell east of Nantucket caused the air to blow from the southwest over the cooler waters around Block Island before reaching Nantucket. The wind sheared rapidly in the lowest 600 m from 220° to 280°. Above this level there was little wind shear. Insolation reached a maximum of 1.6 gm cal/cm^{-2} min^{-1}.

According to the morning radiosonde observation (Figure 23), the lowest 3–4 km of the atmos-

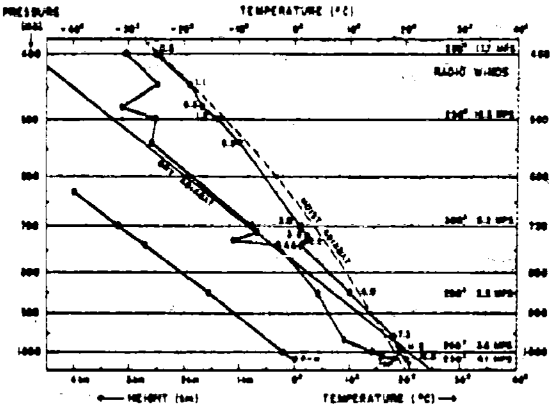

Fig. 23. Nantucket radiosonde observation, 1000 EST, August 15, 1950. Curve marked T is temperature; that marked T_D is dew-point temperature. The curve marked P–H is pressure-height curve. The figures to the right of the temperature curve are mixing ratios in gm/kg. The radio-wind observations made at the same time are entered at the appropriate pressures at the far right.

phere was stratified into four distinct layers. The lowest 400 m had a lapse rate of 0.27°C/100 m, the result of the cool waters. The next 2300 m was less stable (0.80°C/100 m) and presumably represents the remnant of a previously well-mixed ground layer. Overlying this layer is a dry stratum inversion (see Willett, 1935) with a lapse rate of −0.3°C/100 m. The next layer, the base of the free atmosphere, has a lapse rate of 0.53°C/100 m. The soundings taken at 1200 EST (Figures 24 and 25), show that little change occurred in the lapse rate. A value of 0.01°C/100 m was found over the water while a value of 0.74°C/100 m persisted in the air above the land, exclusive of the very surface air. Later at 1325 EST (Figures 26 and 27), a marked change in the character of the air flow over the island was noted and the lapse rate over the island varied from 1.0°C/100 m to 1.50°C/100 m. This change in stability occurred simultaneously with the formation of small cumulus clouds and a chaotic appearance of the cross sections.

The outstanding feature of the flow over the island on this day was the alternation between the

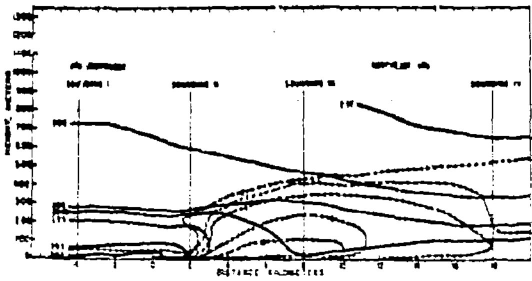

FIG. 24. Cross section made from airplane soundings, Case 5, August 15, 1950 between 1208–1303 BST. Potential temperatures and turbulence index given in units previously mentioned. No clouds present at time of observation.

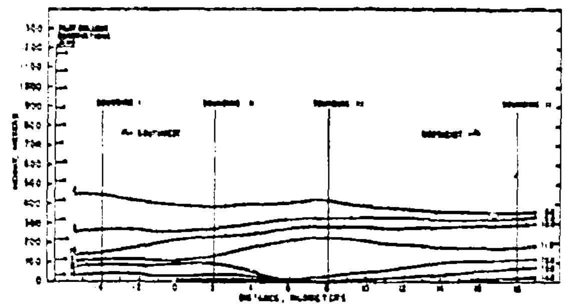

FIG. 25. Cross section made from airplane soundings, Case 5, August 15, 1950. Mixing ratio expressed in gm/kg.

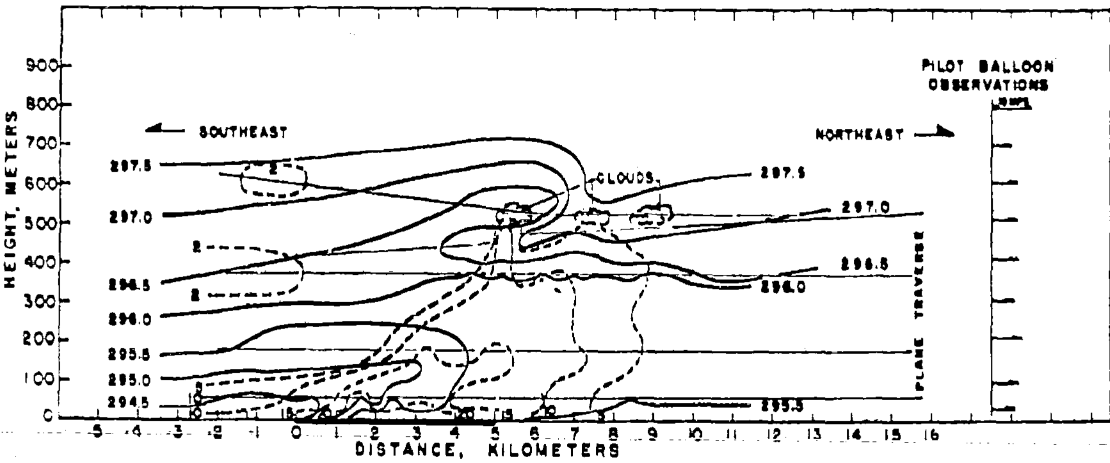

FIG. 26. Cross section constructed from horizontal airplane runs over island, August 15, 1950 made between 1325–1407 EST. Potential temperatures and turbulence index given in units previously mentioned. Small cumulus clouds were forming over leeward part of island. (See Fig. 28.) Approximate position of clouds has been entered on diagram. The airplane traverses are indicated by the light solid lines.

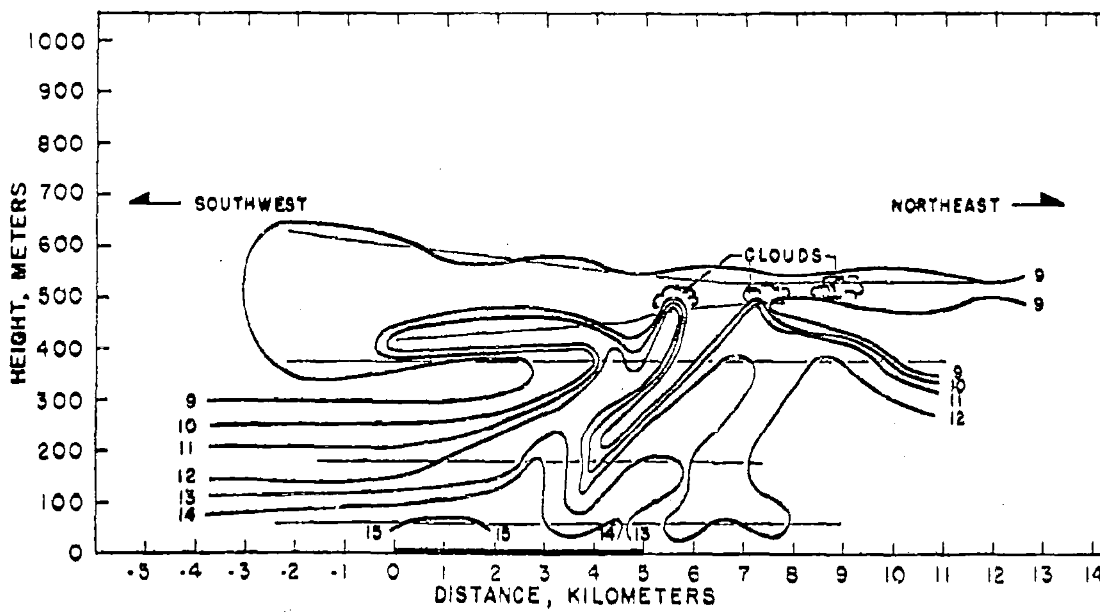

FIG. 27. Cross section constructed from horizontal airplane runs over island, August 15, 1950. Mixing ratio given in gm/kg. Clouds as in Fig. 28. Approximate position of clouds has been entered on diagram.

production and the non-production of cumulus clouds. Cumuli were present over the island until 1000 EST. They then disappeared until, at 1330 EST a few small cumulus with limited vertical development were produced. The four airplane soundings were made while the skies were clear. The horizontal runs were made while the small cumuli were present. The entirely different patterns of the two situations is most striking. In the case with no clouds, both the potential temperature and the mixing ratio lines indicate a smooth flow of air over the island. In the cloud case, it is obvious that convective eddies are present and are associated with the cloud formation. No exact interpretation of the cross section can be made in terms of particular eddies as the horizontal runs are not simultaneous.

The outbreak of the cumulus clouds after 1300 EST can be explained as the result of a change from stability to instability of the lowest 350 m of air over the island. This allowed convective processes to carry moist, slightly warmed air to the level of lifting condensation. It appears that a certain amount of "overshooting" of the air is required to reach the condensation level.

The instability resulted from a combination of the warming of the air upwind from the island, decreasing the lapse rate to 0.33°C/100 m, and of the higher temperatures of the solar-heated land.

Figure 28 is a photograph of the small cumulus forming over the leeward shore of the island. Their small vertical development and localization are apparent.

In searching for an explanation of the observed decrease in the stability of the air, it was noted that the air temperature both at the station on Tuckernuck and upwind from Nantucket increased by 2° to 3°C at the time of reappearance of the clouds over Nantucket. The sea temperature, however, increased by only 0.8°C. Two

FIG. 28. Photograph of small cumulus clouds forming, over leeward shore of island, 1400 EST, August 15, 1950. Prior to 1330, no clouds were formed.

reasons for this sudden heating of the air have been considered. One is the usual warming and drying of air associated with the clockwise shear of the wind at the rear of a high. The other possibility is that solar-heated air arrived over Tuckernuck and Nantucket. The Vineyard was upwind from Nantucket as far as the wind above 1220 m after 1300 EST was concerned and heat could easily diffuse downward into the layer moving from 220°. The turbulence of the air upwind of Nantucket increased with the reappearance of the clouds. This observation supports the conclusion that Marthas Vineyard influenced the air over Nantucket and also substantiates the hypothesis that heat diffused downward, by proving that the ability of the air to transport properties actually did increase.

A comparison of the pilot balloon observations taken at 1000 EST over Nantucket, at 1243 EST over Tuckernuck, and at 2200 EST over Nantucket, shows that the wind above 1220 m shifted from 280° to 250°–260° for several hours and then returned to 270°–300°. This temporary shift was sufficient to bring in air aloft that had not previously passed over the Vineyard and had not had its stability reduced. The same wind shifts were observed at the surface on Tuckernuck Island at about the times of disappearance and reappearance of the clouds over Nantucket.

The theoretical studies of the air flow over an island have demonstrated that a necessary condition for the production of downwind cumuli is a rapid change with height in either the stability or the wind speed of the free air upwind of the island. It is unlikely, however, that these properties of the undisturbed, relatively high-level air stream would fluctuate with time sufficiently to cause the observed alternation between the production and non-production of cumulus. It appears more plausible to related this to changes in the mixed ground layer which is often very sensitive to wind shifts of the type noted (see Stern and Malkus, 1952).[6]

[6] Air Flow over a heated island (II). Woods Hole Oceanographic Institution, Reference No. 52–27. Manuscript report to Office of Naval Research, 1952.

TABLE 12 — CASE 5

TUCKERNUCK SURFACE OBSERVATIONS AUGUST 15, 1950

Time EST	Dry-bulb Temperature °C	Wet-bulb Temperature °C	Wind Direction (degrees clockwise from N)	Wind Speed m/sec	Sea Temperature °C
1000	21.0	19.6	220	0.8	21.2
1100	21.1	19.7	210	1.1	
1200	23.1	20.5	210	0.7	
1300	23.2	20.6	230	1.0	
1400	22.7	20.8	230	1.0	22.0

TABLE 13 — CASE 5

NANTUCKET PILOT BALLOON OBSERVATIONS AUGUST 15, 1950

Time	1000 EST		2200 EST	
Height m	Direction (degrees clockwise from N)	Velocity m sec⁻¹	Direction (degrees clockwise from N)	Velocity m sec⁻¹
0	230	4.1	250	3.2
305	220	3.2	240	9.6
610	250	2.3	260	8.2
915	260	2.3	260	6.8
1220	270	4.1	270	6.4
1525	280	5.5	270	6.8
1830	290	5.5	300	6.4

TABLE 14 — CASE 5

TUCKERNUCK PILOT BALLOON OBSERVATIONS AUGUST 15, 1950. 1243 EST

Height m	Direction (degrees clockwise from N)	Velocity m/sec
35	223	6.1
108	230	7.0
216	232	8.3
315	220	6.0
414	220	6.3
513	220	5.7
612	227	6.7
707	243	5.0
801	243	6.0
890	243	5.5
990	243	6.5
1080	243	6.5
1170	243	6.5
1260	256	5.5
1350	250	6.5
1440	254	5.5
1530	270	5.5
1620	250	5.5
1710	258	6.0
1800	262	6.0
1890	268	7.0

TABLE 15 — CASE 5

WOODS HOLE INSOLATION, AUGUST 15, 1950

Hour (EST)	Insolation (gm cal/cm² hour)	Hour (EST)	Insolation (gm cal/cm² hour)
0600–0700	18.1	1200–1300	90.0
0700–0800	40.1	1300–1400	86.2
0800–0900	59.1	1400–1500	71.1
0900–1000	76.2	1500–1600	52.2
1000–1100	88.0	1600–1700	29.0
1100–1200	96.1		

CASE 5 — AUGUST 15, 1950

SOUNDING 1

Over water, 4 km upwind 1208–1219 EST

Pressure mb	Height m	Temperature °C	Mixing Ratio gm/kg	Potential Temp. °K	Turbulence Index
1018	8	20.1	12.9	292.0	2
1017	15	20.2	13.0	292.4	2
1013	45	20.5	13.0	292.6	2
1012	62	20.6	13.0	293.0	1
1008	95	20.7	12.1	293.5	1
1004	126	20.5	10.2	293.5	1
1001	155	20.5	9.5	293.8	2
997	188	20.2	9.9	293.9	1
993	220	20.2	9.7	294.1	2
990	250	20.0	9.9	294.1	2
986	280	20.3	8.0	295.0	1
983	313	20.2	8.0	295.0	1
979	345	19.7	7.7	294.9	1
972	405	19.7	7.4	295.4	1
969	438	19.4	8.2	295.3	1
965	470	19.2	7.0	295.6	1
962	501	18.8	7.2	295.5	1
958	530	18.6	7.5	295.6	1
955	563	18.3	7.2	295.5	1
951	600	18.2	7.4	295.7	1
948	625	17.9	7.2	295.8	1
944	660	17.6	7.3	295.9	1
941	690	17.4	7.3	295.9	1
937	720	17.1	7.2	296.0	1
934	755	16.9	7.6	296.1	1
930	785	16.6	7.2	296.1	1

CASE 5 — AUGUST 15, 1950

SOUNDING 2

Over island, 3km downwind of windward shore 1220–1233 EST

Pressure mb	Height m	Temperature °C	Mixing Ratio gm/kg	Potential Temp. °K	Turbulence Index
1017	16	21.2	13.7	293.2	not readable
1015	31	21.1	13.4	293.2	not readable
1014	40	21.5	13.9	293.8	not readable
1012	50	21.2	12.8	293.7	not readable
1012	62	21.4	12.8	294.0	not readable
1008	95	21.2	12.6	294.0	not readable
1004	126	20.6	10.9	293.7	not readable
1001	155	20.6	10.2	293.9	not readable
997	188	20.4	10.1	294.1	3
993	220	20.2	10.3	294.4	3
990	250	20.4	9.5	294.5	3
990	258	20.5	8.9	294.6	1
986	280	20.8	8.7	295.1	1
983	313	20.4	7.6	295.1	1
979	345	20.1	8.0	295.2	1
976	376	19.8	8.0	295.1	1
972	405	19.7	7.8	295.1	1
969	438	19.5	7.5	295.5	1
965	470	19.4	7.4	295.6	1
962	501	19.3	7.6	296.0	1
958	530	19.0	7.8	296.0	1
955	563	18.6	7.8	295.9	1
951	600	18.4	7.8	296.0	1
948	625	18.1	7.7	296.0	1
944	660	17.9	7.6	296.2	1
941	690	17.7	7.7	296.2	1
937	720	17.5	7.3	296.5	1
934	755	18.1	7.2	296.5	1
930	785	16.5	7.6	296.1	1

CASE 5 — AUGUST 15, 1950

SOUNDING 3

Over water, 8 km downwind of windward shore 1235–1248 EST

Pressure mb	Height m	Temperature °C	Mixing Ratio gm/kg	Potential Temp. °K	Turbulence Index
1017	15	22.5	12.1	294.5	7
1016	23	22.4	11.2	294.6	8
1015	31	22.2	11.4	294.5	8
1012	62	22.1	11.4	294.5	7
1008	95	21.9	11.2	294.6	10
1004	126	21.5	11.0	294.6	6
1001	155	21.4	11.7	294.7	7
997	188	21.0	11.2	294.6	8
993	220	20.8	11.0	294.6	8
990	250	20.6	10.8	294.8	5
986	280	20.3	10.0	294.9	4
983	313	20.2	9.4	295.0	3
983	318	20.4	9.7	295.1	6
980	328	20.1	9.7	295.1	5
979	345	20.2	8.1	295.2	6
976	376	19.9	8.5	295.2	5
974	391	19.5	8.2	295.2	4
972	405	19.6	8.2	295.2	6
969	438	19.9	7.1	295.9	1
965	470	19.8	7.7	296.1	1
962	501	19.4	7.6	296.1	1
958	530	19.0	7.5	296.1	1
955	563	18.8	7.5	296.0	1
951	600	18.7	7.5	296.4	1
948	625	18.5	7.5	296.5	1
944	660	18.2	7.6	296.5	1
941	690	18.0	7.5	206.5	1
937	720	17.7	7.1	296.5	1
934	755	17.6	7.5	296.6	1
930	785	17.3	7.4	296.8	1

CASE 5 — AUGUST 15, 1950

SOUNDING 4

Over water, 12 km downwind of windward shore 1250–1303 EST

Pressure mb	Height m	Temperature °C	Mixing Ratio gm/kg	Potential Temp. °K	Turbulence Index
1017	15	22.1	13.9	294.1	5
1015	31	22.0	13.2	294.2	4
1012	62	21.6	13.0	294.2	6
1008	95	21.3	12.8	294.2	3
1006	110	21.4	12.0	294.5	5
1004	126	21.5	11.5	294.5	2
1001	155	21.5	11.3	294.7	3
997	188	21.4	10.8	295.0	2
993	220	21.3	10.8	295.1	3
990	250	21.0	10.6	295.1	4
988	273	20.9	10.3	295.2	2
986	280	20.9	10.0	295.3	2
983	313	20.7	9.4	295.5	1
979	345	20.9	7.7	296.1	2
976	376	20.7	7.9	296.2	3
972	405	20.4	7.4	296.3	2
969	438	20.2	8.0	296.2	2
965	470	20.2	7.8	296.6	2
962	501	19.9	7.4	296.5	1
958	530	19.8	7.4	296.6	1
955	563	19.3	7.6	296.6	1
951	600	19.1	7.8	296.7	1
948	625	18.7	7.8	296.6	1
944	660	18.6	7.6	297.0	1
941	690	18.3	7.2	297.0	1
937	720	18.2	7.3	297.1	1
935	735	18.1	7.6	297.2	1
934	755	17.9	7.3	297.1	1
930	785	17.8	7.2	297.4	1

E. Case 6 — August 25, 1950, in which a fog bank dissipated over the island.

On this day a fog bank lying off the eastern shore of Nantucket moved over the island, lifted into fracto-cumulus clouds and then dissipated. The fog bank developed in an air mass that had moved *from* the continent out over the cooler waters of the ocean, stagnated in the center of a high, and had been returned to Nantucket by the low-level easterly winds in the southern portion of the high cell.

The wind sheared rapidly, becoming westerly at upper levels. The 1500 EST Nantucket pilot balloon observation gave a wind at 300 m of 4.6 mps from 60°, veering to 2.1 mps from 210° at 1500 m, with an increasing westerly component aloft. The airplane sounding made 2 km upwind of the island at 1138 EST (see Figure 1 for location) clearly revealed the past history of the air. In the first 100 m, there was a lapse rate of 0.6°C/100 m indicating heating of the air from below, even before it reached the island, by the increasingly warm waters (see Figure 1). From 100–500 m, a strong inversion of 2.5°C remained from the previous cooling of the air. From 500–660 m a lapse of 1.5°C occurred and from 660–750 an inversion of 0.7°C. Above this a steady lapse of about 0.5°C/100 m prevailed up to 3 km in the air that had reached the region from a southwesterly direction. The Nantucket radiosonde, reproduced in Figure 29, revealed the same general air structure, with additional heating from below due to the island causing a dry adiabatic lapse rate in the lowest 300 m. Both the upwind sounding and Nantucket radiosonde showed extreme stratification of the water vapor content of the air.

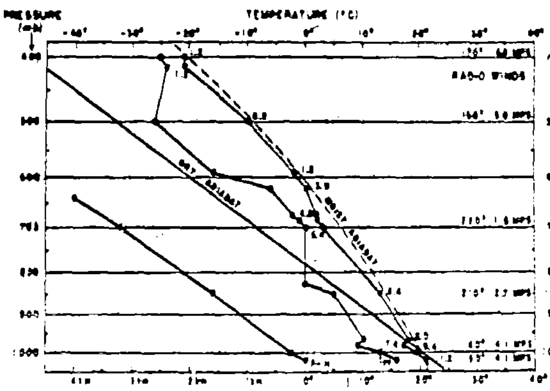

FIG. 29. Nantucket radiosonde observation 1000 EST, August 25, 1950. Curve marked T is temperature; that marked T_{DP} is dew-point temperature. Curve marked P-H is pressure-height curve. The figures to the right of the temperature curve are mixing ratios in gm/kg. The radio-wind observations are entered at the appropriate pressures at the extreme right.

The solar heating was intense as there were only a few middle or high clouds in the area. A maximum insolation rate of 1.5 cal cm^{-2} min^{-1} was measured at Woods Hole in the hour from 1100 to 1200 EST. The accompanying map, Figure 30,

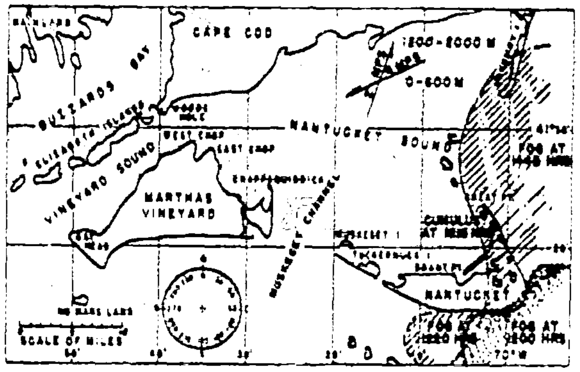

FIG. 30. Map of Nantucket Island showing the extent of the fog bank at three different times on the afternoon of August 25, 1950.

shows the variations in the limits of the fog bank and small ragged cumulus that formed just at its edges. It is apparent from the map that the warm water of Nantucket Sound as well as the heated island are effective in lifting the fog. The water temperature in the Sound is at least 4°C warmer than in the Gulf of Maine where the fog was developed.

The cross sections of potential temperatures, turbulence index and mixing ratio constructed from the spiral soundings made between 1138–1303 EST are shown in Figures 31 and 32. Figures 33 and 34 show similar cross sections constructed from the horizontal traverses made between 1315–1340 EST. A study of these sections shows that the most important effect upon the air of the heating by the island was the substantial destruction of the stratification which had previously been created and maintained by strong stability and rapid wind shearing.

The rather slow (~ 4 mps) passage of the air across the island permitted the building up of a mixed ground layer to heights of about 500 m or higher. Figure 31 shows the high extent of the roughened air and Figure 32 clearly reveals the destruction by mixing of the moisture stratifica-

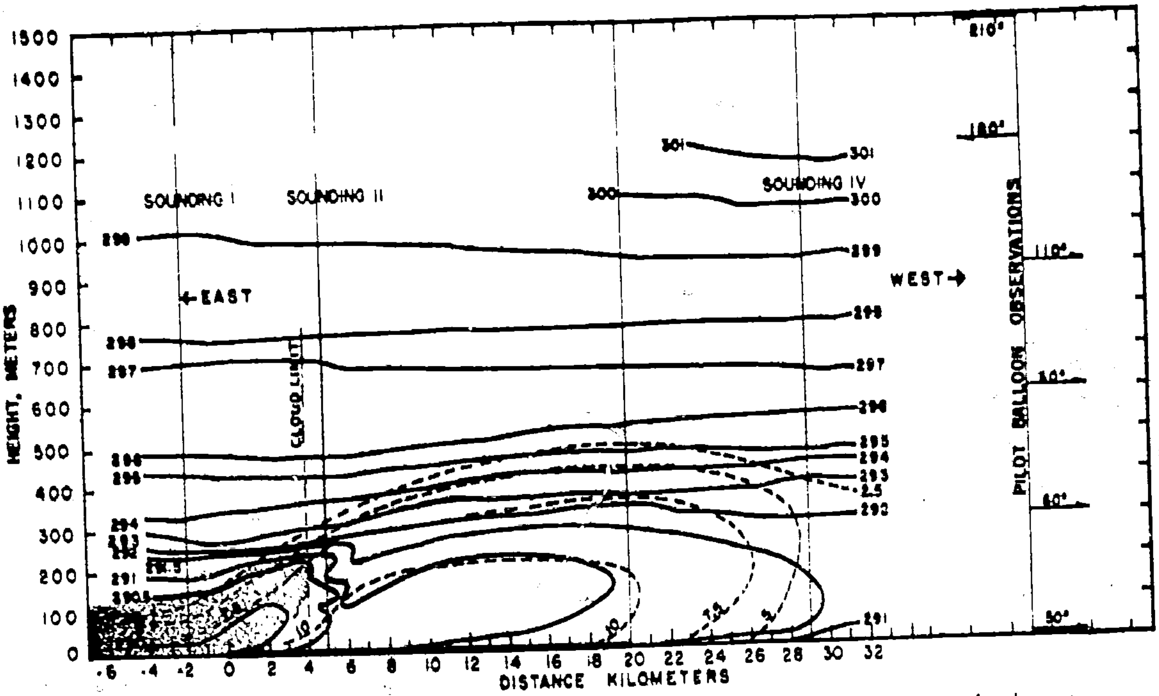

Fig. 31. Cross section made from the airplane soundings between 1138–1303 EST, August 25, 1950, showing potential temperature and turbulence index. Units as mentioned previously. Fog bank and limit of lifted clouds have been indicated by dots and dashed lines. Sounding 3 not plotted since the ascent was not along the same horizontal line as the others.

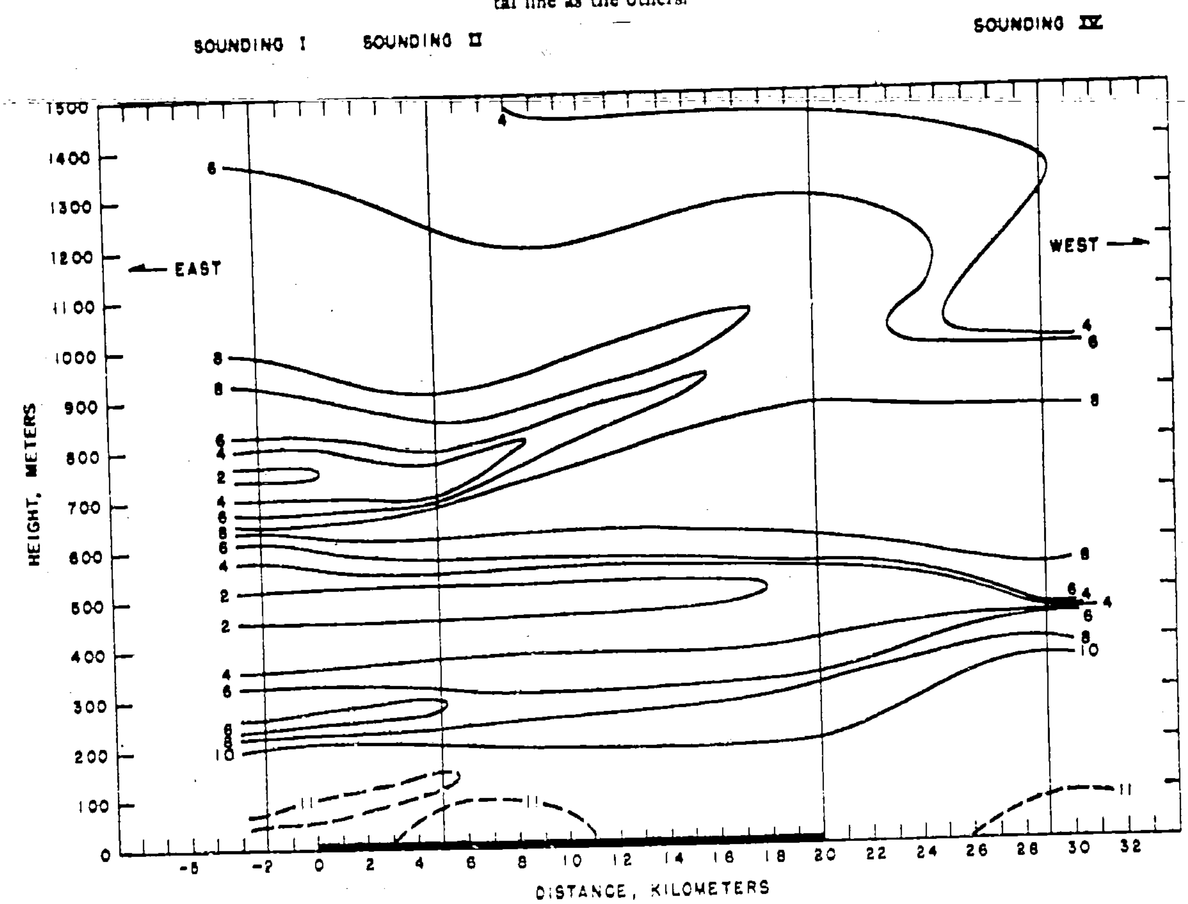

Fig. 32. Cross section presenting mixing ratios measured during airplane soundings, August 25, 1950. Units are gm/kg.

tion between the first and third soundings. The dissipation of the fog is therefore caused by a combined effect of lowering the relative humidity by the added heat and by mixing the air of the lowest "dry wafer" into the moist bottom air. The very

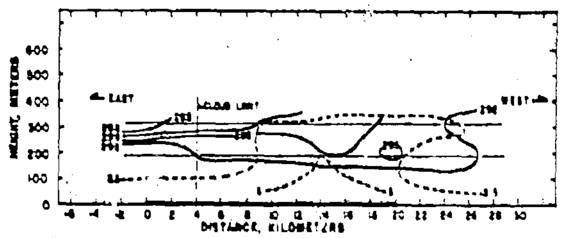

FIG. 33. Cross section made from horizontal airplane runs made between 1315–1340 EST, August 25, 1950, presenting potential temperature and turbulence index.

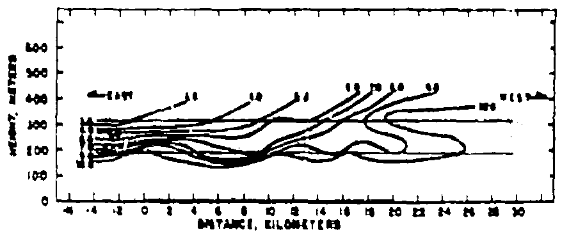

FIG. 34. Cross section made from horizontal airplane runs presenting mixing ratios in gm/kg, August 25, 1950.

small fracto-cumulus which were observed at the forward edges of the fog bank are evidence of the eddying process. By the time of the horizontal runs (Figures 33 and 34), the effect of the island is somewhat weakened, although the spreading of the moisture by mixing is still striking in Figure 34. As the insolation declined, and with it the mixed ground layer, the fog bank gradually covered the entire island. By 1530 EST it had formed a low strato-cumulus overcast.

Although this case is of little value in comparison with the theoretical model, since the air flow was along the long dimension of the island, the wind sheared rapidly, and the initial air stream was so highly stratified, it is nevertheless of interest to observe the effects of heating from below in such a different situation and the part played by the mixed ground layer in the dissipation of a fog bank.

TABLE 16 — CASE 6

NANTUCKET PILOT BALLOON OBSERVATIONS, AUGUST 25, 1950

1500 EST

Height m	Direction (degrees clockwise from N)	Velocity mps
0	050	4.0
305	060	4.5
610	060	3.6
915	110	1.3
1220	180	1.3
1525	210	2.2
1830	210	2.7

TABLE 17 — CASE 6

WOODS HOLE INSOLATION, AUGUST 25, 1950

Hour (EST)	Insolation (gm cal/cm² hour)	Hour (EST)	Insolation (gm cal/cm² hour)
0600–0700	6.1	1100–1200	88.0
0700–0800	10.1	1200–1300	60.1
0800–0900	22.2	1300–1400	42.2
0900–1000	54.0	1400–1500	26.1
1000–1100	72.1	1500–1600	17.2

CASE 6 — AUGUST 25, 1950

SOUNDING 1

Over water, 2 km upwind of windward shore 1138–1158 EST

Pressure mb	Height m	Temperature °C	Mixing Ratio gm/kg	Potential Temp. °K	Turbulence Index
1021	8	18.0	10.9	289.7	8
1020	16	18.1	10.9	289.8	8
1019	23	18.0	10.8	290.0	8
1018	31	17.9	10.8	290.0	8
1017	39	17.9	10.9	290.0	8
1016	47	17.9	10.9	290.0	8
1016	55	17.8	11.0	290.0	8
1015	63	17.6	10.9	290.0	8
1013	78	17.5	10.9	290.0	5
1011	94	17.5	10.8	290.1	3
1010	110	17.4	10.8	290.1	3
1007	125	17.5	10.8	290.3	2
1004	156	17.5	10.6	290.6	1
1000	188	17.6	10.3	291.1	1
999	198	17.5	10.2	291.2	1
998	210	17.3	9.5	291.0	1
996	220	17.4	8.1	291.2	1
994	234	17.1	6.5	291.2	1
992	250	18.2	5.9	292.3	1
989	282	18.8	6.9	293.1	1
984	313	19.1	6.5	293.9	1
982	344	19.2	4.4	294.1	1
979	376	19.3	3.4	294.6	1
975	406	19.3	3.2	294.9	1
972	438	19.3	3.0	295.0	1
968	470	19.5	1.2	295.6	1
965	501	19.9	1.5	296.2	1
961	532	19.8	3.3	296.5	1
958	563	19.4	3.8	296.5	1
954	595	19.0	5.1	296.4	1
951	625	18.5	8.2	296.2	1
947	658	18.3	7.8	296.2	1
944	690	18.6	4.7	296.8	1
940	720	18.8	2.8	297.4	1
937	751	19.0	1.9	298.3	1
933	784	18.9	2.2	298.1	1
930	815	18.7	5.3	298.1	1
927	845	18.1	7.1	297.9	1
923	876	18.2	7.5	298.4	1
920	908	18.1	7.7	298.4	2
917	940	18.1	8.0	298.5	2
913	970	18.0	8.9	298.9	1
910	1000	17.8	7.7	299.0	1

Case 6 — August 25, 1950

Sounding 2

Over island, 5 km downwind of windward shore 1206–1220 EST

Pressure mb	Height m	Temperature °C	Mixing Ratio gm/kg	Potential Temp. °K	Turbulence Index
1016	47	18.7	11.1	290.9	10
1016	55	18.3	11.1	290.4	11
1015	63	18.6	11.3	290.6	11
1013	78	18.1	11.1	290.5	11
1011	94	17.9	10.8	290.4	10
1010	110	18.2	10.7	291.0	10
1007	125	17.7	11.1	290.5	9
1005	140	17.4	11.1	290.3	8
1004	156	17.2	10.4	290.2	8
1004	156	18.2	10.4	291.4	9
1000	188	17.5	10.8	291.0	11
998	198	17.1	10.8	290.6	10
996	220	16.9	9.5	290.6	9
996	225	17.5	10.7	291.4	9
992	250	17.3	8.6	291.5	6
989	282	18.1	5.9	292.5	5
984	313	18.8	6.5	293.8	4
982	344	18.6	4.9	293.5	2
979	376	19.0	4.1	294.2	1
975	406	19.2	3.1	294.8	1
972	438	19.4	2.5	295.1	1
968	470	19.8	1.4	296.0	1
965	501	19.7	1.5	296.1	1
961	532	19.8	2.1	296.5	1
958	563	19.2	5.3	296.3	1
954	595	18.8	7.6	296.1	1
951	625	18.5	8.6	296.2	1
947	658	18.2	8.8	296.2	1
946	673	18.1	8.5	296.2	1
944	690	18.2	6.7	296.5	1
940	720	19.0	2.5	297.5	1
937	751	19.1	2.6	298.0	1
933	784	18.8	6.0	297.5	1
930	815	18.5	7.8	298.0	1
923	876	18.4	8.0	298.3	1
917	940	18.3	7.7	298.7	1

Case 6 — August 25, 1950

Sounding 3

Over water, 19 km downwind of windward shore 1227–1240 EST (not plotted on Figures 31 and 32 since ascent not made on a continuous line with other soundings)

Pressure mb	Height m	Temperature °C	Mixing Ratio gm/kg	Potential Temp. °K	Turbulence Index
1020	16	19.6	10.6	291.4	9
1018	31	19.4	10.6	291.3	8
1016	47	19.2	10.7	291.3	8
1015	63	19.1	10.8	291.4	7
1013	78	18.8	10.8	291.2	7
1011	94	18.7	10.9	291.2	6
1007	125	18.6	10.7	291.5	6
1004	156	18.4	10.7	291.6	6
1000	188	18.4	10.7	291.7	3
996	220	18.2	9.0	292.0	3
992	250	19.0	7.2	293.0	4
990	265	19.2	6.9	293.2	3
989	282	19.0	7.4	293.2	2
986	297	18.8	9.1	294.1	2
984	313	18.6	9.0	293.4	3
983	328	18.9	6.1	293.6	3
982	344	18.8	5.3	293.8	3
979	376	18.8	4.4	294.0	2
975	406	18.7	4.0	294.0	2
972	438	18.6	3.9	294.5	2

Sounding 3 (*continued*)

Pressure mb	Height m	Temperature °C	Mixing Ratio gm/kg	Potential Temp. °K	Turbulence Index
968	470	18.5	3.8	294.6	2
965	501	18.6	2.5	295.0	3
961	532	18.8	2.3	295.6	3
958	563	18.8	6.7	295.8	3
954	595	18.5	7.7	296.0	2
951	625	18.3	8.3	296.0	1
947	658	18.2	8.6	296.3	1
944	690	18.2	8.8	296.5	1
940	720	18.1	8.4	296.7	1
937	751	18.0	8.4	297.0	1
933	784	18.0	8.4	297.2	1
930	815	17.9	8.3	297.4	1
927	845	17.7	8.2	297.4	1
920	908	18.3	7.4	298.6	1
917	940	18.2	7.5	298.6	1
910	1000	18.1	6.7	299.2	1
900	1100	17.6	7.4	299.5	1

Case 6 — August 25, 1950

Sounding 4

Over water, 29 km downwind of windward shore 1246–1303 EST

Pressure mb	Height m	Temperature °C	Mixing Ratio gm/kg	Potential Temp. °K	Turbulence Index
1021	8	19.6	11.4	291.0	not readable
1020	16	19.6	11.2	291.1	not readable
1018	31	19.7	10.9	291.5	not readable
1016	47	19.4	11.2	291.5	not readable
1015	63	19.2	11.4	291.4	not readable
1013	78	19.1	10.9	291.5	not readable
1011	94	19.1	10.9	291.6	5
1007	125	18.8	11.0	291.7	4
1004	156	18.6	10.7	291.6	4
1000	188	18.3	10.9	291.1	4
996	220	18.2	10.4	291.9	4
992	250	17.6	10.6	291.7	5
989	282	17.5	10.8	291.8	5
984	313	17.3	10.0	292.1	5
982	344	17.2	10.4	292.1	4
979	376	17.0	10.4	292.2	3
977	391	16.9	10.8	292.3	2
975	406	18.5	4.6	294.1	2
973	421	17.0	10.4	292.8	1
972	438	18.2	6.8	294.0	1
970	453	18.9	3.7	294.8	1
968	470	19.3	7.8	295.5	1
961	532	19.1	7.7	295.9	1
951	625	19.0	8.8	296.5	0
944	690	18.7	8.7	296.9	0
937	751	18.6	8.1	297.3	0
930	815	18.4	8.2	297.8	1
923	876	18.4	7.9	298.4	1
917	940	18.2	7.7	298.6	1
913	970	18.4	7.2	299.1	1
910	1000	18.5	3.9	299.5	1
907	1032	18.5	3.1	299.7	1
900	1066	18.4	3.1	300.4	1
893	1160	18.4	2.8	301.1	2
884	1250	17.3	2.7	301.1	0
877	1315	17.0	4.1	301.3	1
867	1410	16.3	2.7	301.5	1

F. Case 7 — August 28, 1950, in which very small cumulus clouds were formed.

The synoptic chart on this day showed a polar front north of the region, cutting eastward across the Great Lakes and extending northeastward into a strong low-pressure center between Labrador and Greenland. The Nantucket area was in the moderate southwesterly flow characteristic of the western portion of a high-pressure cell. The air reaching Nantucket had had a 400 mile trajectory over cooler water, commencing as it left the Delaware shore. The sky was somewhat hazy with fine weather cumulus over the Cape and Vineyard appearing at about 0855 EST.

The airplane sounding made at 1200 EST upwind of the island showed an inversion of about 1°C from the surface to 150 m, a lapse rate of 0.65°C/100 m from 150–660 m, another sharp inversion of 2.1°C between 660 and 785 m and above

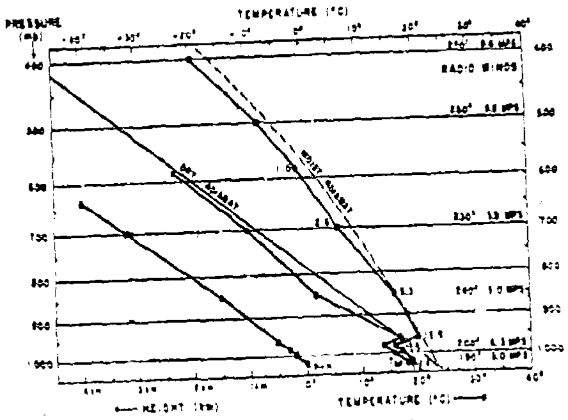

FIG. 35. Nantucket radiosonde observation, 2200 EST, August 27, 1950. Curve marked T is temperature; that marked T_{DP} is dew-point temperature. Curve marked P–H is pressure-height curve. The figures to the right of the temperature curve are the mixing ratios in gm/kg. The radio-wind observations made at the same time are entered at the appropriate pressures at the extreme right.

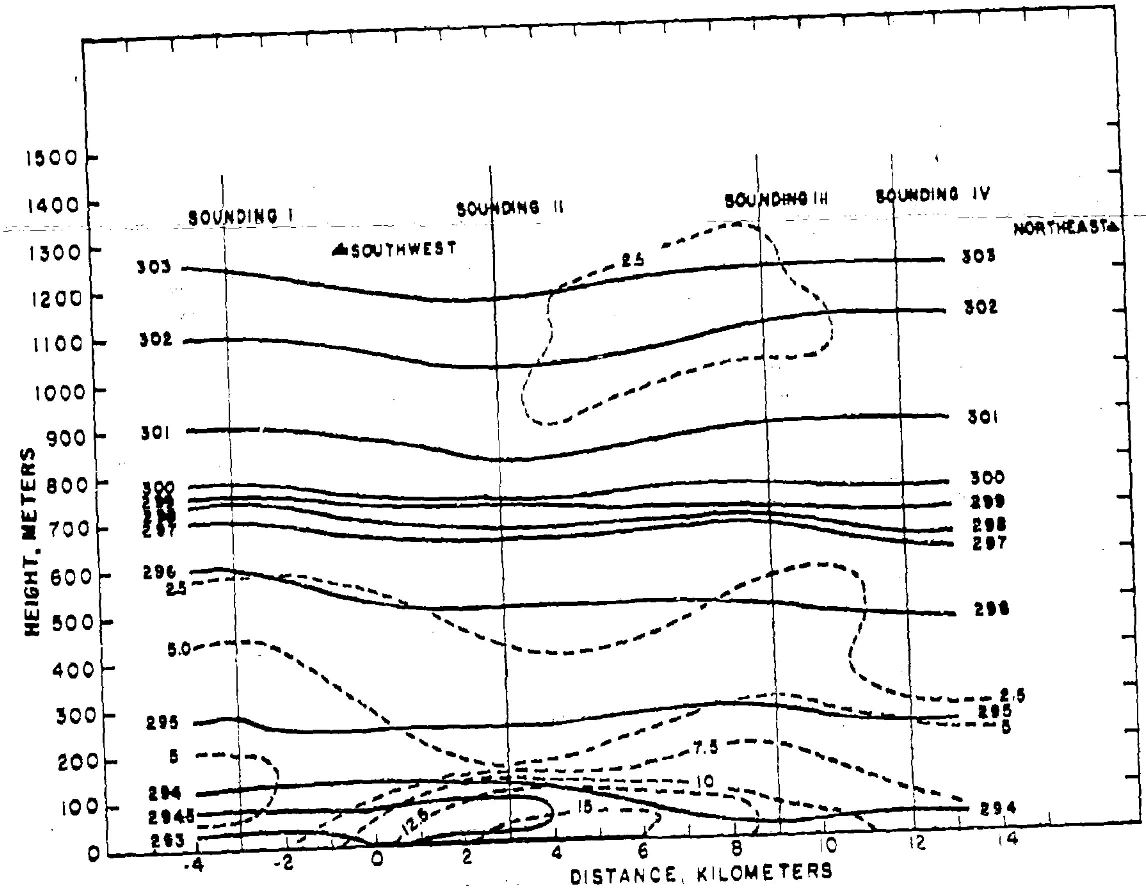

FIG. 36. Cross section constructed from airplane soundings, between 1200–1350 EST, August 28, 1950, showing potential temperature and turbulence index.

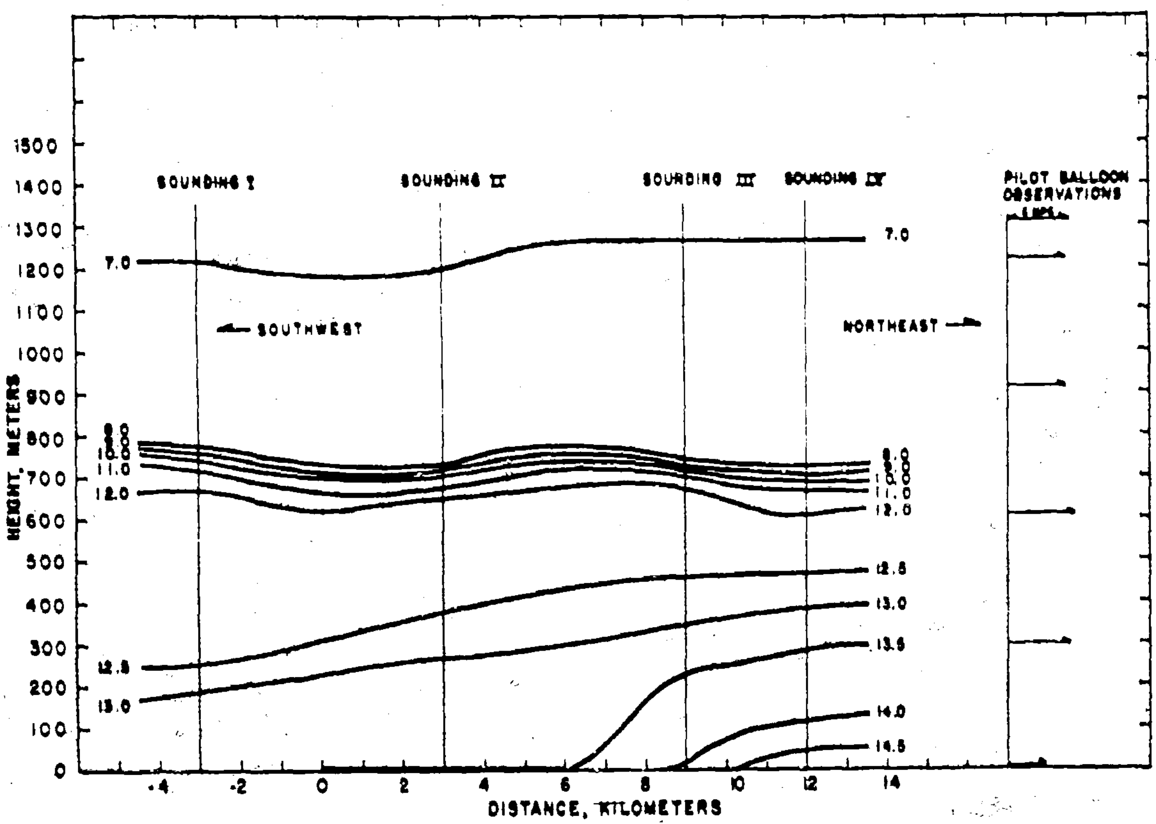

FIG. 37. Cross section constructed from airplane soundings, August 28, 1950. Mixing ratio given in gm/kg.

that a lapse rate of 0.48°C/100 m up to the top of the sounding at 1290 m. The Nantucket radiosonde for the 28th was not available, but that for 2200 EST of the 27th is reproduced in Figure 35. The Nantucket pilot balloon observation (Table 18) showed a southwesterly wind which turned little with elevation, being 3.7 mps from 230° at the surface and 4.3 mps from 240° at 1830 m.

The solar heating of Nantucket was diminished slightly by a small amount of high cloudiness and attained the maximum value of 1.5 cal cm^{-2} min^{-1}. The most interesting feature of this day's observations were the cloud formations. All day long a fog bank maintained itself off the southeast shore of the island. This began to move in over the airport at 1330 EST, forcing the curtailment of the observations. Apparently quite independently of the fog bank, very small cumuli began appearing along the lee rim of Nantucket at 0945 EST. By 1000, the airplane observer noted that rows of several of these small clouds extended out to leeward and that their appearance was "almost like eyebrows".[7] Unfortunately, they were not photographed until 1310, by which time they had lost some of their lenticular form. Figure 38 shows one of these streets stretching out to lee of the northeast shore of the island, with the fog bank off the southeast shore in the background. The cumulus base was observed to be at about 600 m. Since the soundings showed a sharp inversion based at 660 m, a positive area of only 60 m vertical extent was available for their growth. It is significant to note that on this day of rather smooth flow over the island, and only a small region of conditional instability, the cloud forms closely resembled the common type observed in waves to the lee of mountains.

Figures 36 and 37 show cross sections constructed from the four airplane soundings. The inversion based at 660 m is particularly noticeable in both the potential temperatures and mixing ratios. A calculation of the turbulent mass exchange has been made from the soundings, supplemented by the surface observations and water temperatures. The flow of sensible heat into the

[7] Quoted directly from airplane observer's notes.

lower layers was computed from the accumulation of heat as determined from the soundings. Gradients have been found with the help of the surface observations. This step has a large degree of uncertainty as negative gradients of the potential temperature exist only in the lowest 30 m over the land while the airplane only made measurements at 30 m and higher. The results of this work show that in the lowest 30 m in the 0–3 km region the coefficient had the low value of 50 gm cm^{-1} sec^{-1}, while downwind over the remainder of the island and 3 km of water, it attained the value of 270 gm cm^{-1} sec^{-1}. Corroboration of this increase is found in the turbulence index curves which change from 5 to 15.

It is noticed that the greatest increase in the accumulation of water vapor occurs over the island and in the first three kilometers downwind from the island. This area coincides with the region of greatest turbulence and mixing. Downwind of the 9 km mark the turbulence decreases and only a small amount of water vapor is added to the air. Rough calculations based on moisture accumulations show that the coefficient of turbulent mass exchange decreases from a value of 1600 gm cm^{-1} sec^{-1} in the region from 6 km to 9 km to a value of 400 gm cm^{-1} sec^{-1} in the region from 9 km to 12 km. These values were computed for the lowest 450 m.

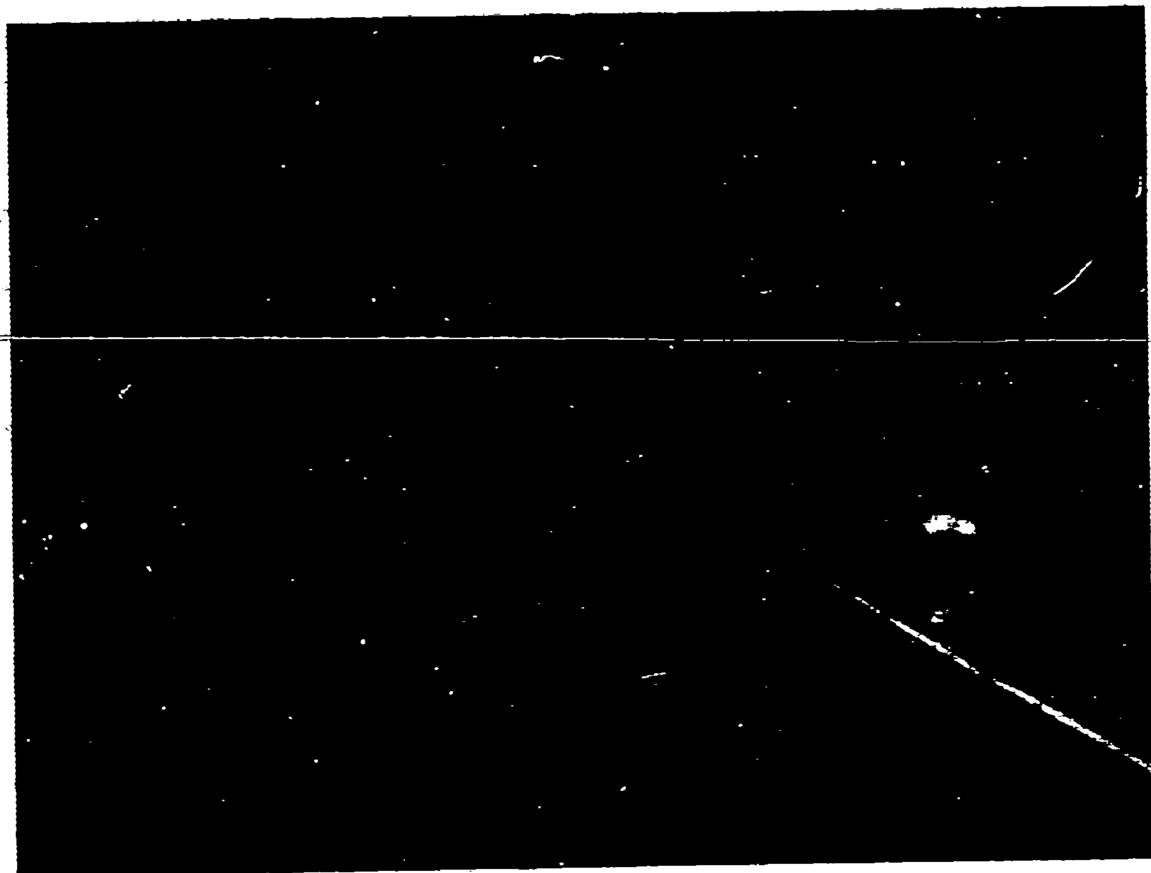

FIG. 38. Photograph of fog lying off the southeast shore of Nantucket. All airplane observations were made in clear air at right of fog bank. Note the street of small cumulus clouds in the foreground, stretching downwind from the east shore (coastline shown).

TABLE 18 — CASE 7

NANTUCKET PILOT BALLOON OBSERVATIONS, AUGUST 28, 1950
1600 EST

Height m	Direction (degrees clockwise from N)	Velocity mps
0	230	3.7
305	230	6.1
610	250	6.7
915	250	5.8
1220	250	5.8
1525	240	4.0
1830	240	4.3

TABLE 19 — CASE 7

WOODS HOLE INSOLATION, AUGUST 28, 1950

Hour (EST)	Insolation (gm cal/cm² hour)	Hour (EST)	Insolation (gm cal/cm² hour)
0600–0700	10.0	1100–1200	89.1
0700–0800	25.1	1200–1300	88.0
0800–0900	54.0	1300–1400	87.0
0900–1000	59.7	1400–1500	74.2
1000–1100	72.1		

CASE 7 — AUGUST 28, 1950

SOUNDING 1

Over water, 3.2 km upwind of windward shore 1200–1216 EST

Pressure mb	Height m	Temperature °C	Mixing Ratio gm/kg	Potential Temp. °K	Turbulence Index
1012	31 U*	19.9	13.2	293.0	5
1005	95 D	20.7	13.3	293.6	2
998	155 U	20.7	13.6	294.2	2
990	220 D	20.6	12.8	294.6	5
983	280 U	20.4	12.4	295.0	5
976	345 D	19.9	12.1	295.4	6
967	420 U	19.4	12.3	295.5	6
962	470 D	18.9	12.3	295.5	3
953	545 U	18.3	12.3	295.8	3
948	600 D	18.0	12.4	296.0	2
941	660 U	17.4	12.2	295.9	1
934	720 D	18.1	11.2	297.4	1
927	785 U	20.5	7.8	300.0	1
921	850 D	20.5	7.3	300.8	1
911	935 U	20.1	7.1	301.2	1
907	975 D	19.5	7.2	301.0	1
901	1040 U	19.3	7.6	301.2	1
894	1100 D	19.2	7.6	302.0	1
887	1165 U	19.1	7.2	302.8	1
881	1225 D	18.6	6.6	302.8	1
874	1290 U	18.1	7.5	303.1	1

* U represents upwind side of helix, D downwind side. Sounding flown according to exacting routine described in Section II A.

CASE 7 — AUGUST 28, 1950

SOUNDING 2

Over island, 3 km downwind of windward shore 1221–1236 EST

Pressure mb	Height m	Temperature °C	Mixing Ratio gm/kg	Potential Temp. °K	Turbulence Index
1009	62 U*	21.1	13.2	293.9	14
1001	126 D	20.6	13.3	294.0	13
994	188 U	20.2	13.4	294.5	3
987	250 D	20.3	13.1	295.0	2
980	313 U	20.2	12.6	295.4	3
973	376 D	19.9	12.5	295.5	2
966	438 U	19.2	12.4	295.5	1
959	501 D	18.8	12.3	296.0	3
952	563 U	18.4	12.4	296.0	2
945	625 D	18.0	12.2	296.4	1
938	690 U	19.7	10.2	298.5	1

* U represents upwind side of helix. D downwind side. Sounding flown according to exacting routine described in Section II A.

SOUNDING 2 (*continued*)

Pressure mb	Height m	Temperature °C	Mixing Ratio gm/kg	Potential Temp. °K	Turbulence Index
931	755 D	21.2	7.6	300.7	1
924	815 U	21.3	7.4	301.5	2
917	870 D	20.4	7.2	301.0	1
911	935 U	20.2	7.4	301.4	2
904	1000 D	19.9	8.1	301.8	1
897	1065 U	19.9	7.5	302.4	1
890	1125 D	19.1	7.7	302.5	1
884	1190 U	19.4	6.0	303.2	2
878	1255 D	18.9	6.8	303.5	1
871	1320 U	18.5	6.9	303.9	1

CASE 7 — AUGUST 28, 1950

SOUNDING 3

Over water, 9 km downwind of windward shore 1240–1255 EST

Pressure mb	Height m	Temperature °C	Mixing Ratio gm/kg	Potential Temp. °K	Turbulence Index
1012	31 U*	22.0	14.1	294.0	12
1005	95 D	21.7	13.6	294.5	8
998	155 U	21.1	13.7	294.5	6
990	220 D	20.5	13.6	294.6	6
983	280 U	20.4	13.1	295.0	7
976	345 D	19.6	13.0	295.0	3
969	405 U	19.5	12.8	295.5	1
962	470 D	19.1	12.5	295.9	1
955	530 U	18.8	12.4	296.1	2
948	600 D	18.1	12.4	296.1	2
941	660 U	18.3	12.2	296.7	2
934	720 D	20.5	7.9	299.5	1
927	785 U	20.8	7.3	300.3	1
921	850 D	20.6	7.3	300.8	1
914	910 U	20.4	7.5	301.1	1
907	975 D	19.6	8.3	301.0	2
901	1040 U	19.9	7.8	300.9	2
894	1100 D	19.4	7.1	302.0	2
887	1165 U	19.3	7.1	302.9	2
881	1225 D	18.8	6.9	303.0	2
874	1290 U	18.5	7.0	303.5	2

* U represents up wind side of helix, D downwind side. Sounding flown according to exacting routine described in Section II A.

CASE 7 — AUGUST 28, 1950

SOUNDING 4

Over water, 12 km downwind of windward shore 1300–1315 EST

Pressure mb	Height m	Temperature °C	Mixing Ratio gm/kg	Potential Temp. °K	Turbulence Index
1011	38 U*	21.7	14.5	294.0	6
1005	95 D	21.4	14.1	294.4	8
998	155 U	21.1	13.8	294.5	6
990	220 D	20.6	13.8	294.7	6
983	280 U	20.6	13.5	295.4	2
976	345 D	20.0	13.2	295.5	1
969	405 U	19.8	12.6	295.8	1
962	470 D	19.3	12.4	296.0	2
955	530 U	19.0	12.2	296.3	2
948	600 D	18.7	12.1	296.5	1
941	660 U	20.2	11.0	298.6	1
934	720 D	20.8	8.1	299.8	2
927	785 U	20.8	7.4	300.4	1
921	850 D	20.7	7.6	300.9	1
914	910 U	20.3	8.0	301.1	1
907	975 D	20.1	7.3	301.5	2
901	1040 U	19.3	7.1	301.2	1
894	1100 D	19.2	7.3	301.9	1
887	1165 U	19.2	7.3	302.8	1
881	1225 U	18.8	6.9	303.0	1
874	1290 D	18.5	7.0	303.3	1

* U represents upwind side of helix. D downwind side. Sounding flown according to exacting routine described in Section II A.

G. Case 8 — September 5, 1950, in which a cold front had recently passed and strong cumulus convection occurred.

The synoptic situation was dominated by the inflow of cold polar air after the passage on the preceding afternoon of an occluded cyclonic system. Nantucket at the time of observation was in a region of rapidly rising pressure in the forward portion of a strong high cell with a gradient wind from the north. There were many indications that the air was being rapidly warmed by the water as it approached Nantucket. The water temperature was about 5°C warmer than that of the lowest air; unlimited visibility and strong low-level turbulence prevailed. Small cumulus appeared scattered uniformly over the waters of the Sound, forming a sky coverage of 1/10. The level of these small clouds was determined accurately from the airplane as it flew from Falmouth airport toward Nantucket between 0850 and 0925 EST. Their bases were at 350 m and tops about 500 m, some higher, with smooth air above their tops. As Nantucket was approached from the north, large swelling cumulus were noted over the island (Figures 39 and 40), and medium-sized swelling cumulus were seen extending at least 8 km to the lee (south) of the island, diminishing to smaller cumulus after about 8 km. Approximately 15–16 km south (downwind) of Nantucket the largest clouds of all were seen, namely a row of at least four black cumulonimbus with well-developed anvils reaching upward to at least 2 km. The observed cloud distribution at about 1000 EST is shown on the map in Figure 41. Time-lapse motion pictures looking eastward from Tuckernuck Island verified its significant features.

The Nantucket radiosonde flight at 1000 EST, reproduced in Figure 42, showed air of very low stability up to 2100 m where a strong inversion was based. Since this flight was made from Nan-

FIG. 39. Aerial photograph of Nantucket clouds taken at 1020 EST, September 5, 1950, from location marked "first plane photo" on the map in Fig. 41. Great Point is in the extreme lower left of the photograph, and Nantucket harbor in the extreme lower right.

FIG. 40. Aerial photograph of Nantucket clouds taken at 1025 EST, September 5, 1950, from location marked "second plane photo" on the map in Fig. 41. Cloud line is oriented approximately north-south. The large cloud on the extreme left is the same cloud appearing near the center of Fig. 39.

tucket airport near the south (downwind) portion of the island, the low-level lapse rate was computed from the first (upwind) airplane sounding in order to be representative of the basic air current before disturbance by the heating of the island. The mean lapse rate for the air below the inversion was about 0.65°C/100 m, while the mean lapse rate from the base of the inversion up to 5700 m was 0.42°C/100 m. The mean mixing ratio of the air below the inversion was about 6.5 gm/kg decreasing rapidly above.

Although no insolation record was taken on this day, one made at Woods Hole a few days earlier indicated that the maximum rate at noon would be about 1.4 gm cal/cm² min if no cloudiness were present. The rate of sensible heat accumulation between Sounding 1 and Sounding 2 (see Figure 1 for their locations), assuming that Sounding 1 was characteristic of the air just at the upwind shore, corresponded to a flux of sensible heat into the air of 0.53 gm cal/cm² min. As shown by the map in Figure 41, this air passed under clouds during a considerable fraction of its travel from the first location to the second. Addition of sensible heat to the air by the island was perceptible on Sounding 2 up to 750 m. Measurements using the heat exchange computer on Nantucket airport, which remained mostly in the clear between two cloud streets to the east and to the west, showed a sensible heat flux to the air of 1.3 gm cal/cm² min, the largest value measured in any of the Nantucket cases. Between Soundings 2 and 3, the air was still accumulating heat corresponding to a flux of 0.29 gm cal/cm² min, and between Soundings 3 and 4 a slight loss was indicated, so small as to be within observational and computational error. If real, it was probably due to cold water upwelling close to the downwind shore of the island. There is some evidence that heat was still being added to the air, although

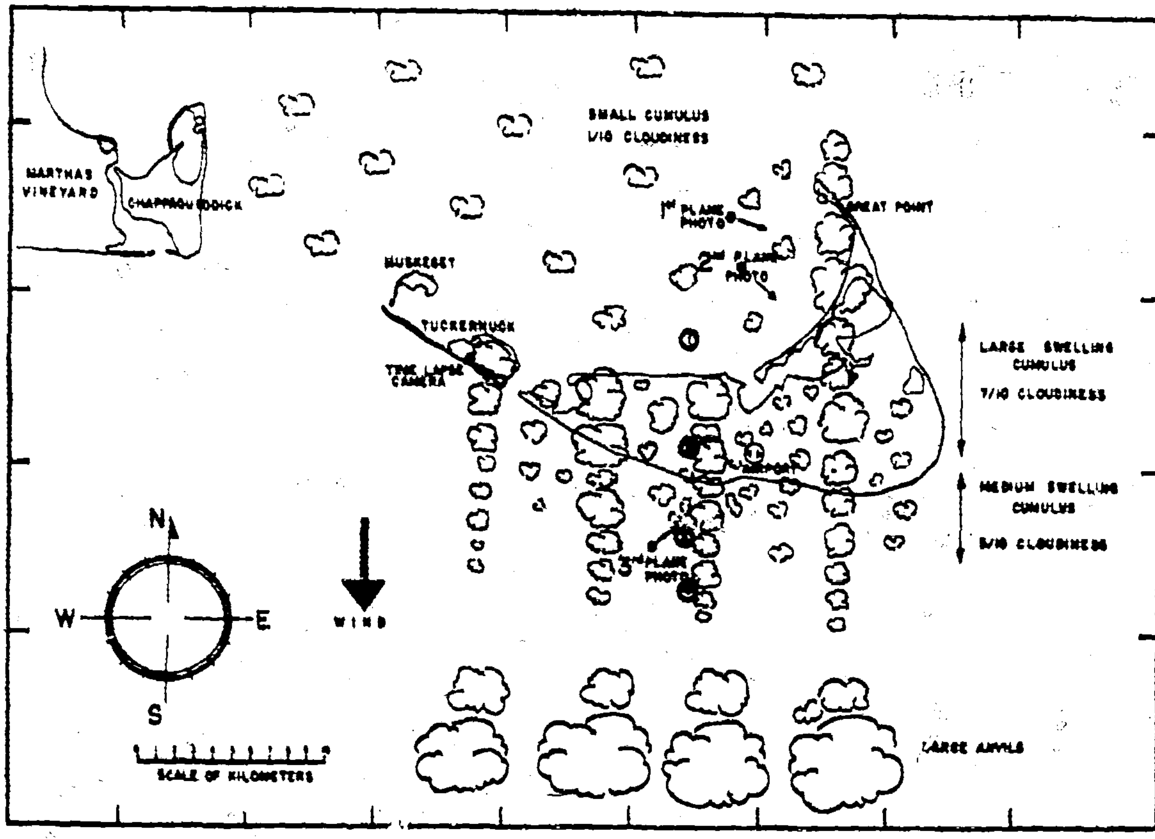

FIG. 41. Map showing schematic configuration of major Nantucket cloud streets during the late forenoon of September 5, 1950. Cloud lines are located accurately from the photographs, soundings, and observer's notes, but the number of clouds was so great that individual clouds are not located exactly or to scale. Time-lapse movies (Fig. 43) were made from the designated position on Tuckernuck Island. Figs. 39, 40, and 44 were taken from the places marked "first plane photo", "second plane photo", and "third plane photo", respectively. The locations of the centers of the helical sounding are shown by the numbered circles (Soundings 2, 3, and 4 pass at least partially within clouds), and most of the horizontal runs were made under or near the same cloud street on a north-south section.

more slowly, as it moved downwind from Nantucket. The first 400 m of the last airplane sounding (about 8 km off the lee shore) showed an adiabatic lapse rate, and the mean water temperature for about 30 km south of Nantucket was probably still slightly warmer than the maximum temperature of the air as it left the island (see Figure 1, Nantucket radiosonde in Figure 42, and the Tuckernuck water temperature in Table 22).

The Nantucket and Tuckernuck pilot balloon observations (Tables 20 and 21) showed a wind practically without shear up to 1200 m, where it gradually began to decrease and back toward the west. The mean wind speed in the lowest 1500 m was 8.2 from 360° (no change in direction throughout this layer). Most of the clouds over Nantucket terminated at about 900 m, within the layer of constant wind. The time-lapse motion pictures, a sequence from which is reproduced in

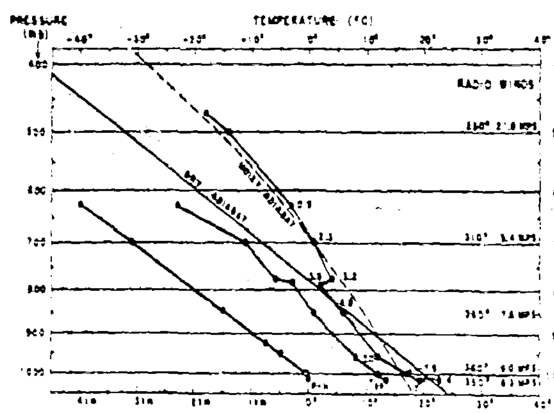

FIG. 42. Nantucket radiosonde observation, 1000 EST, September 5, 1950 (Case 8). Curve marked T is the temperature; that marked T_{DP} is the dew-point temperature. The curve marked P–H is the pressure-height curve. The figures to the right of the temperature curve are the mixing ratios in gm/kg. The radio-wind observations made at the same time are entered at the appropriate pressures at the extreme right.

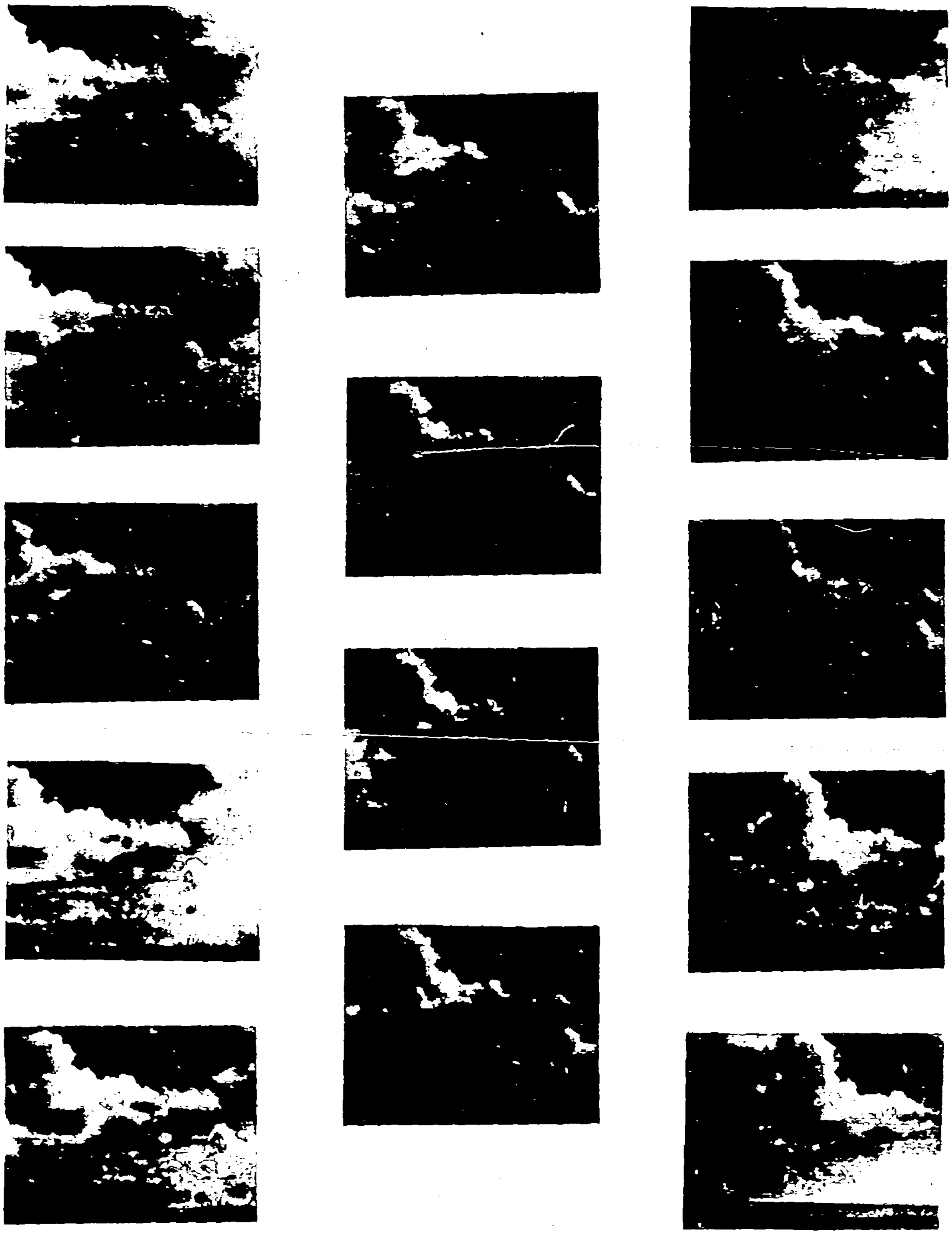

FIG. 43. Sequence from the time-lapse films at about 1100 EST, September 5, 1950. Frames reproduced every six seconds. Camera located and pointed as shown in Fig. 41. Wind blows from left to right (north to south) without shear. Cloud bases at about 600 m; tops about 900 m.

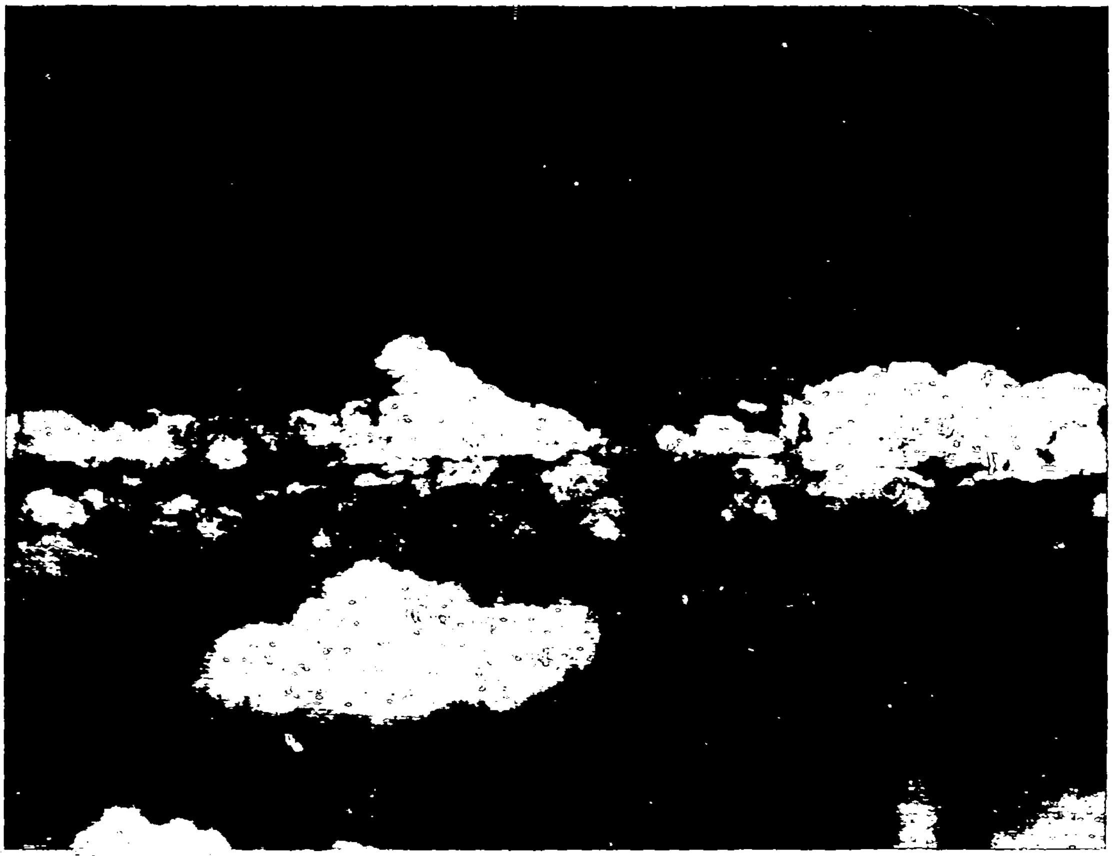

FIG. 44. Aerial photograph of Nantucket clouds made from south of island at 1230 EST. Location given in Fig. 41 by "third plane photo". Most of the clouds shown belong to the street investigated by the soundings and shown schematically on the map in Fig. 41.

Figure 43, showed these clouds growing vertically and symmetrically. A few of the bulging towers reached up to about 1500 m or more, where they developed a pronounced backward slant toward the north (see Figure 44).

Figures 45 and 46 are north-south cross sections over the island constructed from the four airplane soundings. Figure 45 shows isopleths of potential temperature and of turbulence index, and Figure 46 shows dry temperature and mixing ratio. A marked rise in height of the cloud base toward the south was recorded. The heights of the cloud tops, on the average, also rose toward the south, although not with such regularity. The two larger clouds shown were actually flown through in taking the soundings and are therefore reconstructed exactly. The others are reconstructed from photographs. The fact that the tops of the two larger clouds appear colder than their surroundings might at first be attributed to a wetted dry temperature element or some other instrumental effect. Checking of the original records shows that while evaporation from a partially wetted dry bulb may have caused a fictitiously low temperature, evidence exists to the contrary. First, within these same clouds but nearer their bases, the same sensing element gave within-cloud temperatures that were higher than that of the environment. Second, some short horizontal runs made at 1425 (discussed later) through the afternoon clouds over Nantucket, which had higher bases and far higher tops than those of the morning, showed the upper portions of these later clouds to be warmer than their surroundings. The high concentration of isentropes just above the cloud tops on Figure 45 indicates that these morning clouds were overshooting their equilibrium heights. Calculation from the time-lapse film (Figure 43) showed the cloud tower to be rising at only 1 mps. Its top was at 900 m, just the level of the small stable

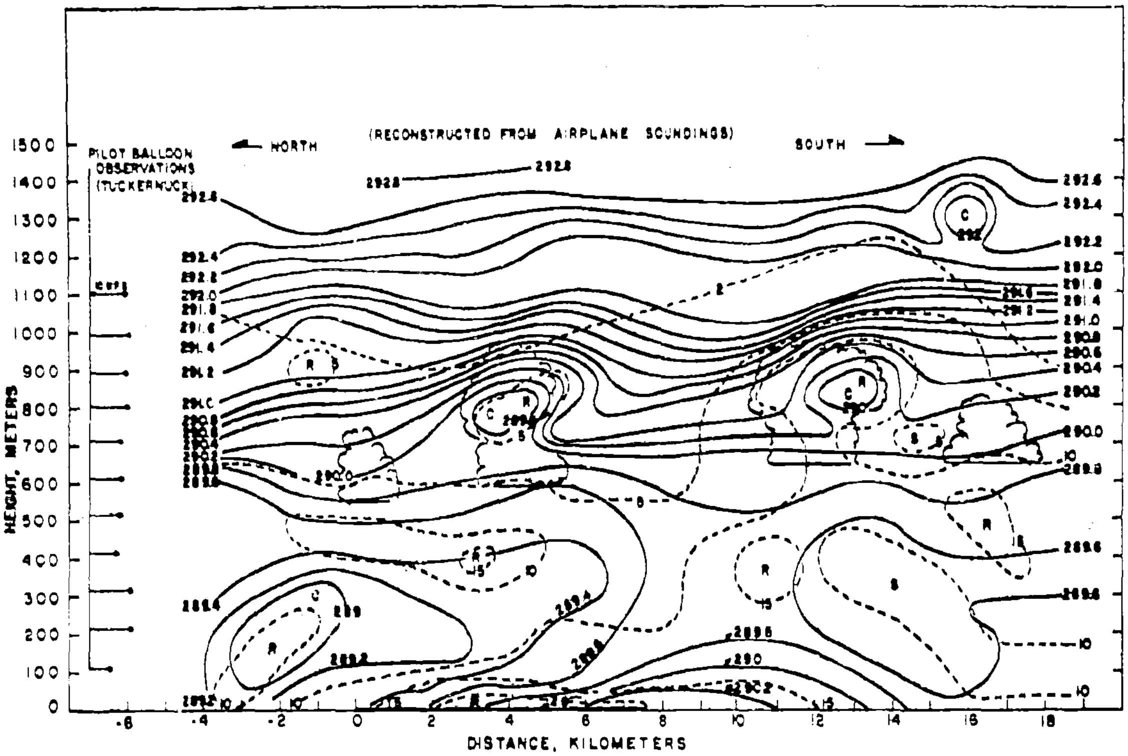

FIG. 45. North-south cross section of the air over Nantucket Island, September 5, 1950, constructed from the four airplane soundings made between 1025–1230 EST. Isopleths of potential temperature and turbulence are shown with the same notation and units as in previous sections.

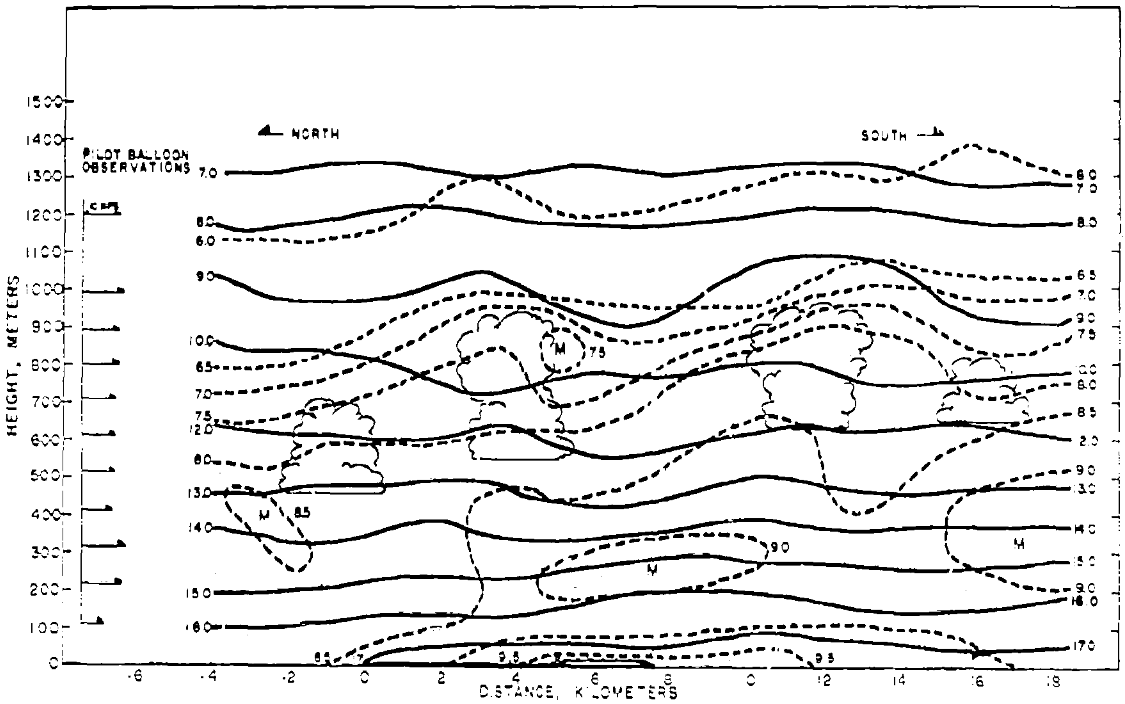

FIG. 46. North-south cross section of the air over Nantucket Island, September 5, 1950, showing temperature and mixing ratio constructed from the same soundings as Fig. 45.

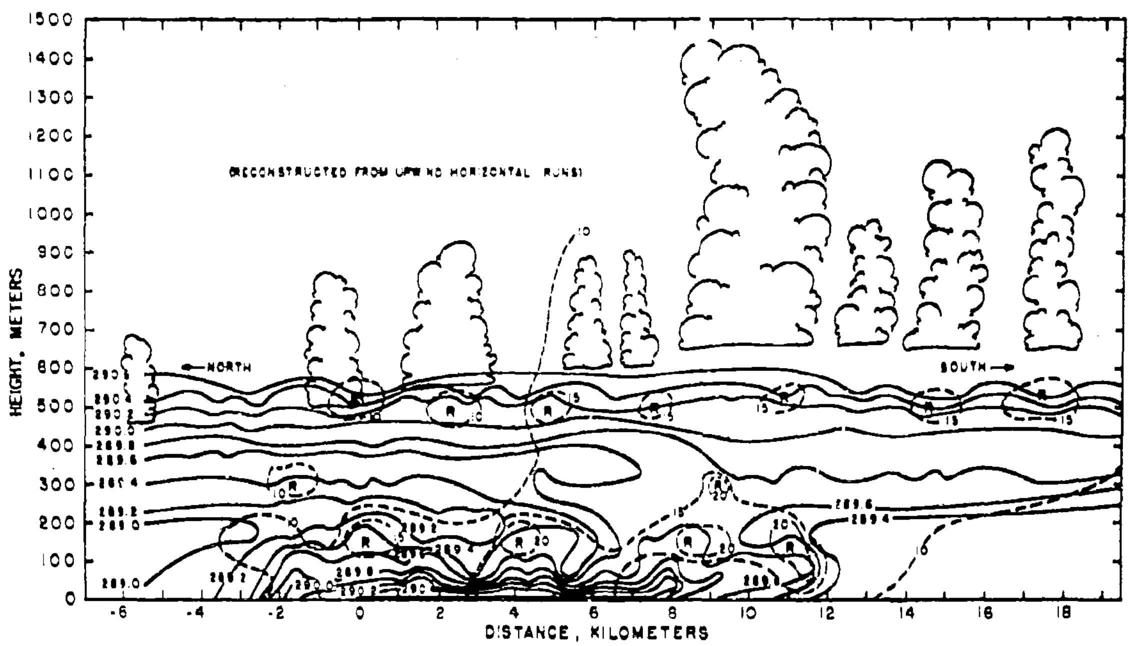

FIG. 47. North-south cross section of the air over Nantucket Island, September 5, 1950, constructed from the upwind horizontal airplane flights, made between 1250–1345 EST. Potential temperature and turbulence index are shown in the same manner as in previous sections. The cloud bases have been located exactly from marks made directly on the flight records.

layer on Figure 46; this and the slow ascent speed are further indications that the tower was overshooting. The small cold region in the upper right of Figure 45 is in a location frequently penetrated by the highest cloud towers before their dissipation.

Figures 47 and 48 were constructed from the horizontal airplane flights along the same cross section. Figure 47 shows potential temperature, turbulence index, and the exact location of the cloud bases recorded during the flights. The highest traverse (5550 m) passed through the two most northerly (upwind) clouds and below the bases of those further downwind. Figure 48 shows the calculated correlation coefficient between dry temperature and turbulence index, after each variable was averaged over 10-second intervals. It has been shown by Bunker (1952) that high values of this coefficient are indicative of convective activity. Up to the 550 m level, the correlation coefficient was computed from the same horizontal runs as shown in Figure 47 (1250–1345 EST). The upper part was computed from the horizontal runs made around and in the cumulus from 1425–1445. The high value of 0.9 correlation was found inside of (near the top) one actively growing cloud tower, which was both warmer and more turbulent than its surroundings. The clouds observed on this occasion have been discussed further by Malkus (1952).

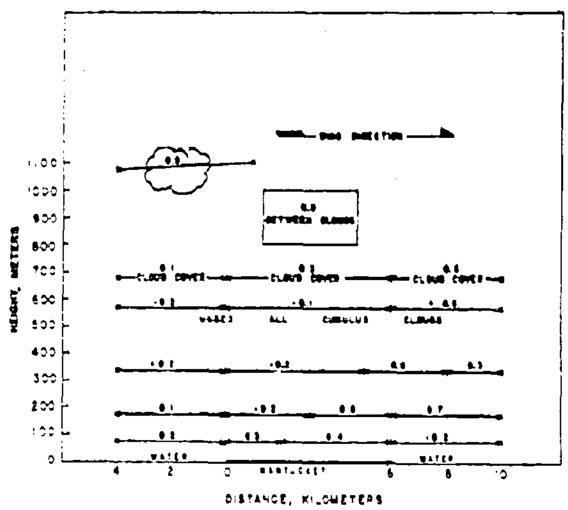

FIG. 48. Cross section showing distribution of calculated correlation coefficient between temperature and turbulence index, from horizontal flights.

TABLE 20 — CASE 8

PILOT BALLOON OBSERVATIONS AT NANTUCKET AIRPORT

1100 EST SEPTEMBER 5, 1950

Height m	Direction (degrees clockwise from N)	Velocity mps
0	350	6.3
328	360	8.9
656	360	8.9
985	360	8.9
1310	360	8.5
1640	360	7.6
1965	010	6.7
2290	350	5.4
2620	320	5.8
2950	310	5.8
3280	310	5.4

TABLE 21 — CASE 8

PILOT BALLOON OBSERVATIONS AT TUCKERNUCK ISLAND

1129 EST SEPTEMBER 5, 1950

Height m	Direction (degrees clockwise from N)	Velocity mps
108	360	6.0
265	358	11.4
414	337	9.0
513	354	9.2
612	004	9.0
707	010	9.0
801	003	10.3
890	003	9.7
990	358	11.0

TABLE 22 — CASE 8

SURFACE OBSERVATIONS AT TUCKERNUCK ISLAND

SEPTEMBER 5, 1950

Time EST	Td °C	Tw °C	Wind Direction	Velocity (estimated) mps	Clouds
1000	18.9	15.4	350	7	4/10 cu
1100	19.4	16.0	350	7	4/10 cu
1200	19.0	15.4	350	8	6/10 cu
1300	20.2	16.4	350	7	6/10 cu
1400	19.0	15.6	350	7	5/10 cu

Water temperature at 1000, 19.6°C. No middle or high clouds.

CASE 8 — SEPTEMBER 5, 1950

SOUNDING 1

Over water, 2 km upwind of windward shore 1025–1040 EST

Pressure mb	Height m	Temperature °C	Mixing Ratio gm/kg	Potential Temp. °K	Turbulence Index
1012	31 U*	16.5	8.1	289.1	10
1001	126 D	15.8	8.2	289.2	8
994	188 U	15.0	8.3	289.1	9
987	250 D	14.4	8.5	288.8	15
980	313 U	14.5	8.1	289.4	8
973	376 D	13.7	8.4	289.3	8
966	438 U	13.1	8.6	289.3	10
959	501 D	12.8	8.4	289.6	7
952	563 U	12.2	7.8	289.5	6
941	625 D	11.8	7.7	290.0	5
938	690 U	11.8	7.3	290.2	7
931	755 D	11.4	7.0	290.3	4
924	815 U	11.3	6.3	291.0	8
917	870 D	10.8	6.3	291.0	4
911	935 U	10.5	6.2	291.3	6
904	1000 D	9.7	6.3	291.1	3
897	1065 U	9.7	6.2	291.7	2
890	1125 D	9.4	6.0	291.9	2
884	1190 U	8.9	5.8	292.4	2
878	1255 D	8.5	5.8	292.6	2
871	1320 U	8.1	5.2	292.5	2

* U represents upwind side of helix, D downwind side. Sounding flown according to exacting routine described in Section II A.

CASE 8 — SEPTEMBER 5, 1950

SOUNDING 2

Over island, 3.25 km downwind from windward shore 1138–1151 EST

Pressure mb	Height m	Temperature °C	Mixing Ratio gm/kg	Potential Temp. °K	Turbulence Index
1012	31 U*	17.3	9.3	289.7	10
1005	95 D	16.5	8.8	289.5	15
998	155 U	15.7	8.5	289.2	8
990	220 D	15.2	9.0	289.4	10
983	280 U	14.6	8.7	289.3	7
976	345 D	13.9	8.6	289.2	5
969	405 U	13.5	8.6	289.4	13
962	470 D	12.9	8.5	289.4	10
955	530 U	12.5	8.4	289.6	9
948	600 D	11.8	8.1	289.6	9
941	660 U	11.7	7.9	289.9	5
934	720 D	11.4	7.4	290.4	6
927	785 U	10.4	7.7	289.8	6
921	850 D	10.2	8.0	290.0	4
914	910 U	10.3	7.2	290.8	6
907	975 D	9.9	6.5	291.0	2
901	1040 U	10.1	5.9	291.7	2
894	1100 D	9.6	6.1	291.9	2
887	1165 U	9.2	6.1	292.1	No
881	1225 D	8.6	5.9	291.9	trace
874	1290 U	8.1	6.0	292.4	of
868	1355 D	7.8	5.7	292.6	turbu-
861	1420 U	7.4	5.5	292.8	lence.

* U represents upwind side of helix, D downwind side. Sounding flown according to exacting routine described in Section II A.

Case 8 — September 5, 1950

Sounding 3

Off lee shore, 6.75 km downwind from windward shore

1155–1210 EST

Pressure mb	Height m	Temperature °C	Mixing Ratio gm/kg	Potential Temp. °K	Turbulence Index
1012	31 U*	17.8	9.6	290.2	16
1005	95 D	16.8	9.1	289.9	10
998	155 U	16.4	8.7	289.9	8
990	220 D	15.4	8.9	289.5	10
983	280 U	14.9	9.0	289.6	14
976	345 D	14.1	8.7	289.5	5
969	405 U	13.8	8.9	289.7	5
962	470 D	13.0	8.4	289.5	9
955	530 U	12.7	8.8	289.8	6
948	600 D	12.1	8.4	289.8	12
941	660 U	11.6	8.5	289.9	8
934	720 D	11.3	8.2	290.2	10
922	830 U	10.8	8.0	290.5	5
917	870 U	9.8	8.1	290.0	3
907	975 D	10.6	6.4	291.7	6
901	1040 U	10.4	6.2	291.9	2
894	1100 D	9.9	6.4	292.[illegible]	3
887	1165 U	9.3	6.3	292.0	3
881	1225 D	8.7	6.1	292.0	2
874	1290 U	8.3	6.0	292.5	2
868	1355 D	7.8	5.9	292.7	3

* U represents upwind side of helix, D downwind side. Sounding flown according to exacting routine described in Section II A.

Case 8 — September 5, 1950

Sounding 4

Over water, 13.75 km downwind of windward shore

1218–1230 EST

Pressure mb	Height m	Temperature °C	Mixing Ratio gm/kg	Potential Temp. °K	Turbulence Index
1012	31 U*	17.2	9.1	289.6	10
1005	95 D	16.7	8.8	289.7	9
998	155 U	15.9	8.5	289.5	10
990	220 D	15.7	9.0	289.8	10
983	280 U	14.9	9.0	289.6	14
976	345 D	14.2	9.1	289.5	13
969	405 U	13.7	9.2	289.6	13
962	470 D	13.3	9.1	289.7	10
955	530 U	12.6	8.9	289.8	13
948	600 U	12.0	8.7	289.8	12
941	660 U	11.8	8.4	290.0	9
934	720 D	11.2	8.0	290.1	6
927	785 U	10.8	7.9	290.2	5
907	975 D	9.6	7.0	290.8	2
897	1065 U	9.5	6.4	291.2	2
890	1125 D	9.3	6.2	291.9	3
884	1190 U	9.0	6.1	292.2	1
878	1255 D	8.2	6.1	292.3	1
871	1320 U	7.6	6.2	292.0	1

* U represents upwind side of helix, D downwind side. Sounding flown according to exacting routine described in Section II A.

IV. SUMMARY OF NANTUCKET OBSERVATIONS, SUMMER OF 1950

	Case Date	2 8/8/50	3 8/9/50	4 8/14/50	5 8/15/50	6 8/25/50	7 8/28/50	8 9/5/50
	Occurrence of Cumulus	Many	None	Many	1st period None 2nd period Slight	Non-convective Fracto-Cumulus	Very small lenticular	Many
Lower Layer	Depth (m)	1000	150	935	300 200	500	500	2100
	Upwind Lapse rate °C/100 m	+0.85*	−2.66	+0.70	+0.01 +0.36	−0.36	+0.25	+0.65
Upper Layer	Depth (m)	500	1050	320	450 400	500	745	3600*
	Upwind Lapse rate °C/100 m	+0.30*	+0.62	+0.59	+0.77 +0.83	+0.42	~0.0	+0.42
	Maximum Insolation ($cal/cm^2 min$)	1.3	1.2	1.4	1.6	1.5	1.5	Missing (est. 1.2)
Mean wind	Layer (m)	0–1000	0–1200	0–900 900–2100	0–1000	0–900 900–1800	0–1800	0–1500
	U	North 3.7 mps	10 mps from WSW slight turning toward W	1.2 mps southerly 3.0 mps northerly	6.3 mps southwest turning to west with height	3.3 mps northeasterly 2.1 mps south southwesterly	5.2 mps SW	8.2 mps from 360°. No change in direction.
	Evidence of Vertical Oscillation	Preferred locations of cloud development ~1.5 km apart	Downdraft indicated by dry region at lee shore	Definite lee waves $\lambda \leqq 1$ km	Downdraft indicated at lee shore. Possible indication of lee waves by small cumulus	Updraft possibly indicated by rise in isentropes 2 km inside windward shore.	Updraft at 600 m at lee shore indicated by small clouds. Those downstream spaced closer than 1 km	Long, large amplitude lee waves suggested by formation of cumulonimbus ~17 km downwind
Lifting Condensation Level based on lowest point on upwind sounding (~35m)		~850 m*	323 m	438 m	313 m	340 m	220 m	690 m (a parcel at 440 m needs only 160 m lifting for saturation)

*From Nantucket radiosonde.

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